TELESCOPE MAKING 40

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The magazine *for*, *by*, and *about* telescope makers!

Spring 1990

Telescope Making #40

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Editor: Richard Berry
Associate Editor: Peter Ceravolo

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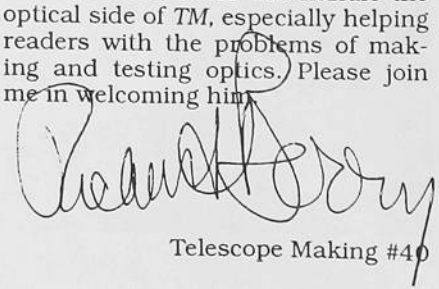
Cover: Bob Cox's enduring legacy to the telescope making community is the example of helping others. Bob's interest, enthusiasm, and knowledge gave thousands of us the impetus to build our own telescopes, and the desire to repay our debt by helping others to build their own. A special tribute to Bob, illustrated with many of Bob's own pictures of the greats of telescope making and astronomy, begins on page 28.

Editorial

TM#40 marks ten years of publishing *Telescope Making*. It has been an extraordinary decade—a decade that in fact took more than eleven years to complete. In that first issue we wrote, "We see *TM* as a magazine that will help people share their ideas and learn from each other. That's why we've called TM 'the magazine by, for, and about telescope makers.' You—its readers—are also its authors. You, and the telescopes you build, are its subject matter." Bob Cox deserves much of the credit for that guiding philosophy, and I believe that the Letters section in this issue demonstrates how fully we met that goal we set for ourselves.

I have asked Peter Ceravolo of Ottawa, Ontario to serve as *Telescope Making*'s new associate editor. Peter describes himself as a professional optician and an amateur telescope maker. He got started in what is now his profession as an amateur, and he knows first-hand the ATM's enthusiasms and frustrations.

Peter has shown himself most willing to share his experience and skills with amateur astronomers. In future issues, Peter will handle the optical side of *TM*, especially helping readers with the problems of making and testing optics. Please join me in welcoming him.



Letters

Ross Null Test Correction

Dear Richard/I wish to thank you for the excellent job you did on our Ross null test article in *TM#39*. I hope the Ross null test proves as useful as the Dall null test has been for so many years.

Unfortunately, I made a mistake in the ordinate values of Figures 10 and 11, as was kindly pointed out to me by Nelson Chow of Ontario, Canada. The ordinate values as printed in the article did not take into account the Δn normalization factor, and are 50 times smaller than they should be. Thus, Figure 10 should have ordinate values ranging from +100 to −100, while the Figure 11 ordinate should range from +400 to −600.

Instead of having an excuse that this article was prepared in too much haste, in fact the opposite situation is the case. Peter Ceravolo and I first met in April of 1986, at Organ Pipe Catus National Monument in southern Arizona, while observing Halley's comet. Peter suggested the Ross mull test article and I agreed to quickly do the calculations. It actually took about 3 years to finish the job, and get the data plotted by a good friend Rich Solstad. All the communication between the three of us was done by letter or phone calls. And although we all checked things numerous times, sometimes having too much time to edit and proofread for mistakes is not too good either. Thus, in my earliest hand plots of Figures 10 and 11, I made the notice to myself to change the ordinate, but unfortunately forgot to ever do it.

I sincerely hope this has not caused anyone reading *TM#39* any problems. Thank you once again for your continued excellent support of the ATM community!

David E. Stoltzmann
368 Ninth Street
Bayport, MN 55003

Corrector Shell Wanted

Dear Mr. Berry/ I am writing to ask the assistance of *Telescope Making*'s readers for an unusual problem. Our group is in possession of an f/2.1 spherical mirror 12 inches in diameter—and we don't know what to do with it!

Well, to be more exact, we are considering several optical configurations using fast spherical primary mirrors and believe that a Maksutov-Cassegrain is the most attractive option. However, the meniscus shell would have to be made of BK-7 glass, at least 11 inches diameter, and least 1.5 inches thick to allow for the very deep sagitta. Besides the problem of high cost of an astronomical-quality, fine-annealed disk of BK-7 of the necessary diameter and thickness, there is also the problem of producing highly accurate radii of curvature on the concave and convex sides of the meniscus. The second problem, i.e., extreme accuracy, is certainly formidable but we have made several good telescopes and believe we can handle it successfully.

What we would like from your readers are sources for the BK-7 blanks already molded to about the necessary radii of curvature for the f/23 or f/15 Gregory-Maksutov design. Such molded blanks were ordered by the hundreds through the Maksutov Club in a bulk purchase engineered by Allan Macintosh in 1957. I believe the blanks were required to be BK-7 and 11 inches in diameter. It would defy all laws of probability if every one of those blanks currently resides in a working telescope!

Therefore I am asking for anyone who knows the whereabouts of any of those blanks to please write or call me. We would be very grateful for any assistance.

Bob Crews
Louisville Astronomical Society, Inc.
715 North Barbee Way
Louisville, Ky. 40217

Wanted: Good Home for Telescope

Dear Richard/My collection of *Telescope Making* magazine is among my most prized possessions. I've been making telescopes for forty years and was never so happy as when you started publishing *Telescope Making*. Let me thank you for all the effort you must have put into the project.

From talking recently with Mr. Warren Offult, I've decided to contact you about my problem. I'll just lay out an abstract here so you can decide where to file this inquiry. I have an orphan, twenty-four inch telescope for which I have to find a home. The telescope was designed and built by experts and should serve some organization very well. I would like to donate it to some capable organization that could make use of its many features. It is free of financial encumberances and even packed in a semitrailer ready for shipment. End of abstract.

There is a long story and many drawings, pictures, slides and computational materials connected with this telescope. The telescope is not complete. Some of the parts are here at Lake Zurich. The full thickness mirror is ground and polished to curve, but not figured to sphere. The corrector is in blank form as is the eight-inch secondary mirror.

The following items are located here at Lake Zurich: the 24-inch x 4.5-inch-thick mirror, the mirror grinding and polishing machine, the 8-inch x 3.25-inch-thick corrector blank, the curve generator for generating the corrector curves, the eyepiece turret and eyepiece holder, grinding and polishing compounds and pitch, a flexowriter for making the drive control tapes, and 600 slides showing construction of the telescope. The semi trailer with the telescope is located at Piscataway, New Jersey. I have all sorts of further information that I would be glad to pass on to anyone interested.

Richard Ulmes
575 Courtland Drive
Lake Zurich, IL 60047

Second Opinion on Ross Null Test

Dear Richard/ I disagree with David Stoltzman's and Peter Ceravolo's assertion that the Dall null test has "many disadvantages" compared to the Ross null setup. I would say, it's the other way around. A major one is the fact that the light traverses the Ross lens twice, necessitating that its surface quality be twice as good as (and a price tag much higher than) that of the Dall lens, which is traversed only once. The Dall test has one significant shortcoming and that is the fact that its correction is mediocre, especially for large, fast mirrors. Nevertheless, one may be able to produce better large mirrors with a Dall test than by the method.

For those who wish to play by professional standards, even the Ross setup just isn't good enough. There are several methods available, utilizing two or even three lenses instead of one, such as the two-lens method by A. Offner which is far more accurate (residual aberrations can be completely eliminated for a true null), expensive and elaborate. And, as in the Ross setup, the light traverses the Offner lenses twice, doubling their surface errors.

Since they seem to like the Ross setup, it would be a good idea if, in addition to their article, Stoltzman and Ceravolo provided readers with the information as to how much a good Ross lens would cost, where to get it, and to what accuracy. I don't necessarily think that the Ross (or any other small lens) null test is the most practical approach for amateurs. The need for null tests involving small lenses is a practical approach to suitable for large, observatory-size mirrors which cannot be autocollimated by matching flats or other methods, and tests (or even offshoots like the caustic test) are simply not accurate enough for the precision expected of professional systems.

For amateurs who intend to make lots of precision optics and wish a simple, reliable method, I suggest they invest their money (or time, if they are good at making optics) in an optical flat and test everything by double-precision autocollimation. For those more reluctant to make such an investment, try a good, smooth, high focal ratio collimating mirror for single-precision work. In either case, there are no lenses to procure, no exact distances to maintain, no separa-

Letters

tions to figure out. Both methods use one set of optics and are universally applicable to single-element, as well as compound optical systems.

Mladen Vranjican
232 Carrie Drive
Franklin, VA 23851

We Have Optical Glass!

Dear Richard/In *TM#39* one of your readers was looking for suppliers of optical glass. We [i.e., U.S. Precision Lens] sell 6-inch f/10 and f/15 refractor blanks for $100.00 a set. These are BK-7 and F-2 grade B and already generated to specific radii.

Although we have only a limited quantity available, we expect to get more. We can also do a custom design for $150.00. The designs and performance data are available on request.

Ed Jones
(Representing U.S. Precision Lens)
610 Woodland Drive
Cincinnati, OH 45244

Glass from Amateur Optics

Dear Richard/ With regard to the letter from Herbert Highstone in *TM#39*, go back to *TM#27* page 50 for an ad from Amateur Optics in England for a source of refractor lens kits. Andrew Sorenson of Jefferson, Iowa, made a telescope from this kit, *TM#36* pages 12 through 19. I looked through this scope at Astrofest 88 and it was optically excellent.

The kits are designed for the Littrow design which many are interested in for planetary work. I wrote Amateur Optics in the spring of 1987 and found their information catalog very good and am just now ready to order a kit and make a lens. I am currently using an apochromatic refractor from Astro Physics and really am pleased with it.

Gene Roeschlein
5117 N. Hartman Dr.
Indianapolis, IN 46226

Mirror Challenge

Dear Richard/ In many ways *Telescope Making #39* was special. The articles and letters were outstanding. The letter by Leon Knott, immediately following Bryce Hartwell's buyers beware of commercial optics message, made it perfectly clear that amateurs can make their own high quality optical surfaces.

I have asked Mr. Knott to explain the method or methods he used to conclude that his otherwise impeccably smooth 20-inch mirror is good to 1/16-wave at the wavefront, or 1/32-wave at the surface, and to state whether this is peak-to-valley or not. In the former case, the maximum deviation from parabola would not exceed 1/64-wave. Such explanation would be both beneficial and interesting to seasoned mirror-makers as well as to those prospective ones who are tired of returning commercial optics and receiving worse replacements and who are seriously contemplating making their own.

Mladen Vranjican
232 Carrie Drive
Franklin, Va. 23851

— In fairness to Mr. Knott, the halftone reproductions in TM#39 *were substandard (the printer has apologized for the terrible job) and the delicate Foucault shadows on Knott's mirror were very poorly rendered. A full answer to Vranjican's questions will appear as a story in a future issue of* TM. *Knott's response follows. —RLB*

Dear Mr. Vranjican/ I would like to begin with the matter of knife-edge placement that you raise in your letter to me. A focogram is capable of revealing far more information as to surface smoothness, than any other method. The fact that it is essentially a permanent record of such information is just one other positive trait of the process. However, when I set up an optical surface for a photo, I spend a great deal of time finding a knife-edge setting that seems to present the most information to the film. Should this be, in every case, the seventy percent zone? I am unwilling to attempt to provide an answer to this question, being incapable of offering mathematical or empirical corroboration. I have enclosed an original print of my focogram; perhaps you'll note that the reproduction in the magazine gives a false impression of shadow crest placement.

Next, our testers. When we started we were using the old "workhorse" Foucault tester sold by University Optics. This tester uses a fixed light source; it is also difficult to use with a slit, as some of our mirror makers prefer, due to the inclination caused by the rotating knife-edge action. While a large number of Carolinian amateurs are still using this device, I have switched to a moving source tester that uses a dial indicator and a microscope stage for movement in both axes (provided by Jim McCauley, who makes a living as a metrologist, one who makes tiny measurements with super-sensitive instruments. Jim's work is referenced back to U.S. Bureau of Standards masters).

With this tester I am able to repeat knife-edge readings to within 0.001 inches with complete reliability. Howard Brewington, who uses a similar tester, routinely brings mirrors which he has tested in his shop to me for testing as well. Invariably, any test results and his will differ in no zone by greater than 0.0015 inches. We feel that no systematic error could remain inasmuch as his test takes place 85 miles away and he keeps his results hidden until I have mine at hand. Naturally, we are aware that we can claim no wavefront error whose deviations are less than the resolution of our test repeatability. While our minds are boggled at the tiny increments we are measuring, we are constantly kept assured by Jim McCauley, who routinely makes measurements on a molecular level by measuring liquid turbidity and who backs us up. He is assisted in that by the expertise of Jim Rouse, who was making mirror reductions back in the 1970s.

As to the mirror reduction process, we use several. We first strive to hit the numbers in the plain old r-squared-over-2R formula. This is made easier by our insisting on figuring a mirror only after it is a VERY good sphere. By starting at only this point we can hit the numbers by using well made laps and normal figuring strokes.

It is by no means rare for us to figure a mirror that hits the numbers dead on the money at every zone. With mirrors that do this we need no further reduction; such a mirror is a good one indeed. I Might add that we are fanatics as regarding edges and surface accuracy (reference my focogram, which is "average" in quality).

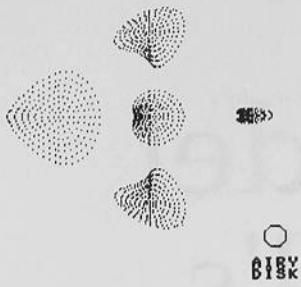
We put it this way: Get the edge RIGHT! Put the numbers ON THE MONEY! and KEEP IT SMOOTH!

Secondly, we routinely use the Millies-Lacroix graphs. This helps us to see the surface profile more readily than can be done by looking at a series of numerical columns. By taking the M-L tolerances and cutting them in half (we usually work between f/4 and f/5) we can usually assure a good mirror as well. If we fall slightly off the numbers yet are still within the tolerance envelope, we make every effort to remain on the same side of the envelope. Remember, our testers use dial indicators which we can zero on our reference zone before making other readings. If we keep our zonal tolerances to within the M-L tolerances, and are using a focal ratio from f/4 to f/5, we end up with mirrors that are easily diffraction limited. However, we wouldn't know that if we didn't continue our reduction through to a mathematical certainty. In order to do this we faithfully adhere to three authorities, Jean Texereau, Bob Follett, and Dick Suiter.

Texereau is really tough for non-mathematicians—and most amateurs aren't. Suiter's treatment of Texereau's Test Data Sheet should accompany any mirror sold that claims a wavefront error of better than 1/4-wave. Even with Suiter it's pretty tough going for the average amateur; without Suiter it's all but impossible.

Follett provides a very fine method that helps obviate much of the arduous button punching of Texereau and

KUTTER TRI-SCHIEFSPIEGLER F/14.7



INCREASED M2-M3 SEPARATION

BUCHROEDER TRI-SCHIEFSPIEGLER F/20

Suiter; he uses a graphical approach that really helps to determine direction of slope and thus makes profile interpretation easy for subsequent figuring steps.

To further validate my 1/16-wave statement as to my 20-inch, Jim Rouse used a system he derived, in part, from Neale Howard's book. Testing my mirror using Texereau/Suiter, Follett, and Rouse's methods *all* gave a wave-front error of 1/16-wave. (All of this of course, is dependent upon my ability to faithfully repeat knife-edge readings, and again, that has a resolution, at this time, of 0.001 inches.) I might add that all the difficult pencil and calculator work can be eliminated by the simple use of Dick Suiter's GENMIR.2 mirror reduction program.

While the foregoing doesn't answer your step by step injunction, it does have the redeeming value of fact. Amateur mirror-makers here in the Carolinas are painfully aware of the need for a simple, straight-forward, simply arithmetic mirror reduction process. Currently Jim Rouse, Jim McCauley and myself (with invaluable help from Gil Stacy, of Savannah, Georgia) are involved in trying to accomplish just that. *Telescope Making* will indeed receive a article if we are successful.

Again, thank you for such an interesting letter. I hope that I have answered, at least in part, your concerns and those of *TM*'s readers.

M. Leon Knott
Curator of Physical Science
Museum of York County
4621 Mt. Gallant Road
Rock Hill, SC 29732

Refining the Kutter

Dear Richard/ My project for this winter was to have been a tilted component telescope. I envisioned a Yolo type telescope, with a toroidal surface polished into both elements. I thought it might be accomplished with a warping harness, attached during figuring, to a groove cut into the edge of the mirrors. The scenario would go something like this: Grind and polish to a sphere just sufficiently to test, attach harness *à la* Art leonard, warp the right amount, return if necessary to fine grinding, polish to final figure, remove harness. In theory, the warp put in by the harness, and ground back out, should reappear in equal amount when the harness is removed. The real unanswered question was, and still is, will this expedient do anything to ameliorate the anamorphic distortion and toroidal field curvature common in these systems?

Since I wanted to try something novel, I needed a way to check optical performance before I undertook actual construction. To this end, I began improving a ray trace program I wrote years ago on a TRS-80, upgraded to a VIC 20, and just last year, translated over to a CBM 64. This program has kept growing through change after change. First, I needed to trace tilted components, then sagittal rays, and finally, skew rays. I use equations from Conrady, Kingslake, and Rutten and van Venrooij. To verify accuracy, I compare results from the newest versions, with the known answers from older versions of the program, with hand calculations I did 15 years ago, with traced examples in books, etc., etc.. The work is ever ongoing.

The single biggest headache I have run into, and the reason for this letter, is the published data for the Schiefspiegler telescopes designed by Anton Kutter. All other designs I have traced, i.e., those of Richard Buchroeder and Jose Sasian, have fallen right on the numbers. These systems obviously were designed on computers. On the other hand, Anton Kutter's famous designs were done before even pocket calculators existed. He must have relied heavily on primary aberration theory and logarithm tables. Along with each of his designs comes a series of instructions for collimating away the last vestiges of aberration. Instructions such as these are necessary even with the computer designs of today, due to the unlikelyhood of producing all radii to required accuracy, or getting a long air space perfect.

As an example, let's examine Kutter's tri-Schiefspiegler design from *TM#16*. It's impossible to plot a spot diagram with the published dimensions because the back focal length is wrong. The plots are out of focus and swollen. We must refocus, as any observer would do at the telescope. The first spot diagram is the result of refocusing. It shows the center and edges of a field the size of the full moon in a 6-inch f/14.7 system. The large size of the central star image is due almost entirely to astigmatism, hence is nearly round. Furthermore, the true back focal length of the system exceeds Kutter's own criterium. (*S&T* Feb. 75) By moving the tertiary back from the secondary, the residuals lessen and at the same time, the back focal length shortens to within the range specified by Kutter.

The second diagram is for the repositioned tertiary. Note the smaller central image, and the more uniform sizes of the field images. I'm not suggesting that every owner of a 6-inch tri-Schiefspiegler rush out and move his tertiary mirror back 1.23 inches. Rather, what I am suggesting is that this second set of spot diagrams is more nearly representative of the performance of a "properly adjusted" telescope. It's disheartening to see the cold precision of the computer wreak havoc with the careful hand calculations of an old master.

For comparison, I also traced the 6-inch tri-Schiefspiegler designed by Richard Buchroeder and published in *TM#28*. The field size is the same half-degree but the f/ratio is 20 instead of 14.7. This is obviously a well designed system.

For those who can generate spot diagrams, here are the necessary parameters. For the original tri-Schiefspiegler, enter a back focal length of 26.6698 inches and a focal plane tilt of 8.725 degrees. To examine the change from respacing, enter a new secondary to tertiary distance of 19.63 inches. The new back focal length is then 25.5696 inches and focal plane tilt is 8.718 degrees.

I am very much indebted to Harrie Rutten and Martin van Venrooij for their excellent treatment of the skew ray trace in "Telescope Optics—Evaluation and Design". I was disappointed that the spot diagram for the catadioptric Schiefspiegler had inadvertently been replaced by the spot diagram for the tri-Schiefspiegler. A word of caution for anyone contemplating writing a skew trace program for their home computer. On page 257, make sure that the direction of the normal is correct before evaluating Vh. This point is not clear from the order in which the equations are

Continued on page 44

A Scale Model of Herschel's Uranus Telescope

Telescope makers usually build full-size telescopes. But that's not always necessary. As part of my participation in Astronomy Day at the Stamford Museum and Nature Center, our local museum, I constructed a scale model of the 6-inch reflector William Herschel used to discover the planet Uranus.

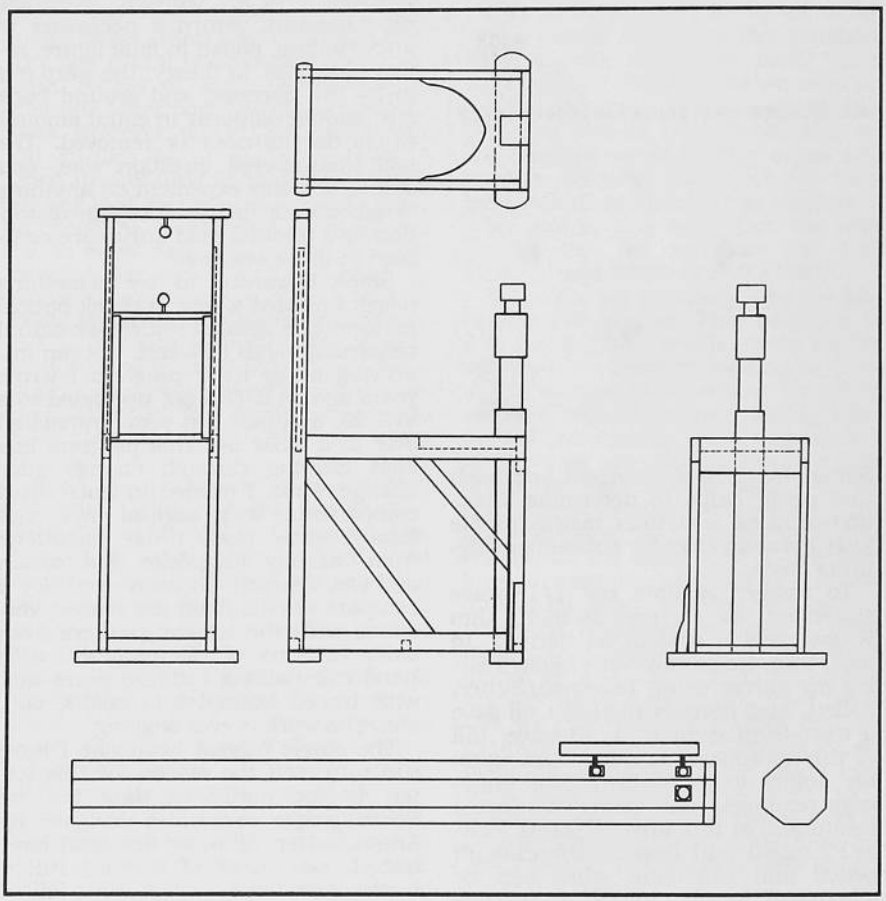
The model is based entirely on a photograph that appeared in the feature story "William Herschel: Pioneer of the Stars," published in ASTRONOMY, November 1988. I made a scale drawing by taking measurements directly off the photograph. It came out almost exactly 1/12th scale, or what is known as doll house scale.

Except for the pulleys on the rear elevation slide, I left out the operating mechanisms off the drawing because including them would have resulted in a hopeless clutter.

The model is of bass wood with a few metal fittings. I used readily available model supplies for the scene. A real mirror lurks at the base of the octagonal 7-inch long tube. The model is 3 inches wide, and stands 8 inches high.

I incorporated the telescope into an imaginary set on Herschel's patio in Bath, England on that fortuitous night, March 13, 1781.

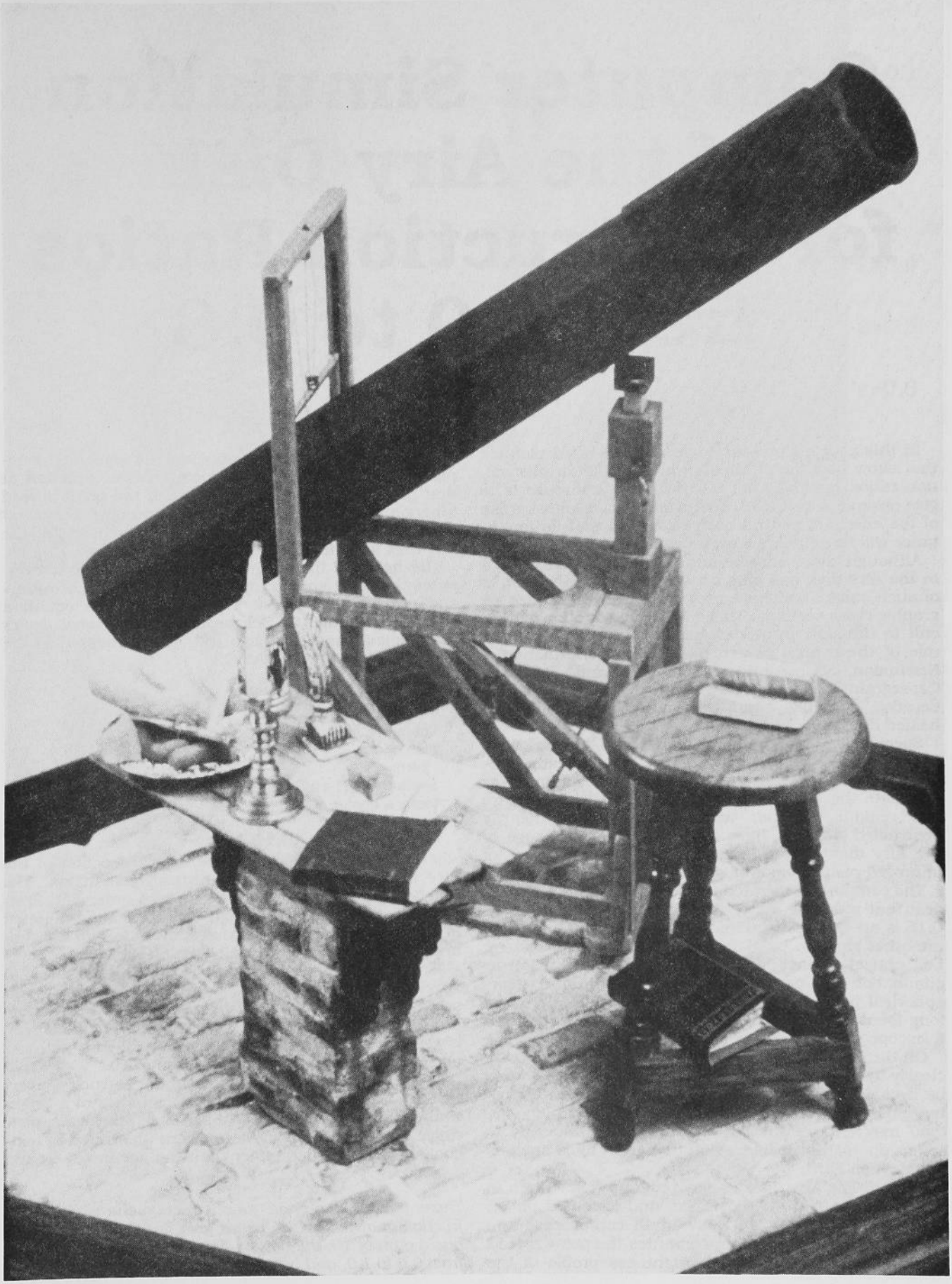
Herschel had wheeled his telescope into position outside so that its optics would cool to air temperature. His stool is pulled up to the eyepiece and on the nearby table are his references, note paper, eyeglasses, and a midnight snack. He's all ready for what he believes will be a routine evening of structured observing.



Herschel himself is not in the scene -- he has gone back inside for a heavy coat. Little does he realize that in a few hours he will make history. Never again will mankind recognize the same old and comfortable solar system.

Ferdinand Miller, Jr
585 Ponus Ridge Rd
New Canaan, CT 06840

Astronomical history is largely overlooked when we plan projects for public consumption. Too often we forget that a lot of discoveries were made and catalogs compiled by individuals using equipment which is crude by modern standards. Scale models help the public understand what astronomy is all about. Photograph by Ed Steinerts.



Computer Simulation of the Airy Disk for Obstruction Ratios from 0.0 to 0.8

In this article I present computer-generated pictures that show how the diffraction image looks for obstruction ratios ranging from 0.0 to 0.8. My purpose is to give observers and telescope makers an intuitive grasp of the effects of central obstruction, so that its importance will be neither exaggerated nor minimized.

Although the theory behind the distribution of light in the Airy disk has long been understood, the results of such calculation have previously been presented as graphic cross sections. This type of presentation is difficult to translate into telescope performance. Thus the role of the central obstruction in the performance of Newtonian, Cassegrain, Maksutov, and Schmidt-Cassegrain telescopes has remained obscure for some decades, and has been the subject of considerable heated debate.

Specifically, the debate has focused on the size of the maximum allowable central obstruction. Optical perfectionists have gone to extreme lengths to minimize or eliminate the central obstruction so that the aperture will remain pristine, while apologists for heavily obstructed systems have pointed to the shrinkage of the Airy disk with a large obstruction as evidence of improved resolving power.

The computer-generated images I have produced suggest that reducing the central obstruction much below 0.15 is an exercise in diminishing returns unless there are other gains to be made in an unobstructed system, i.e., optical surface smoothness and the reduction or elimination of aspherics. The long radii and near-spherical figures of the mirrors in Schiefspieglers and long-focus Newtonians may be more significant than telescope makers have generally assumed.

On the other hand, central obstructions over 0.40 are clearly deleterious to the diffraction images, and should be avoided for contrast-sensitive tasks such as planetary observation. Furthermore, obstructions much over 0.50 may enlarge the diffraction figure sufficiently to soften photographic images on fine-grain films such as Kodak Tech Pan.

Method The Airy disk display program was written in and compiled with Turbo Basic, and executed on an 8MHz XT clone with an 8087 math coprocessor and CGA graphics. The program computes the point spread function, that is, the radial brightness profile of the Airy disk. Then for every pixel on the screen, it compares the brightness of the point spread function at that point with a random number. If the point spread function is greater than the random number, then that pixel is illuminated. A somewhat grainy image of the Airy disk is formed in about two minutes time.

The heart of the program is the routine that computes the point spread function as a function of radius and central obstruction. This is defined in equation 10.1.10 of Daniel J. Schroeder's *Astronomical Optics* (Academic Press, San Diego, 1987), and realized as the following algorithm in BASIC:

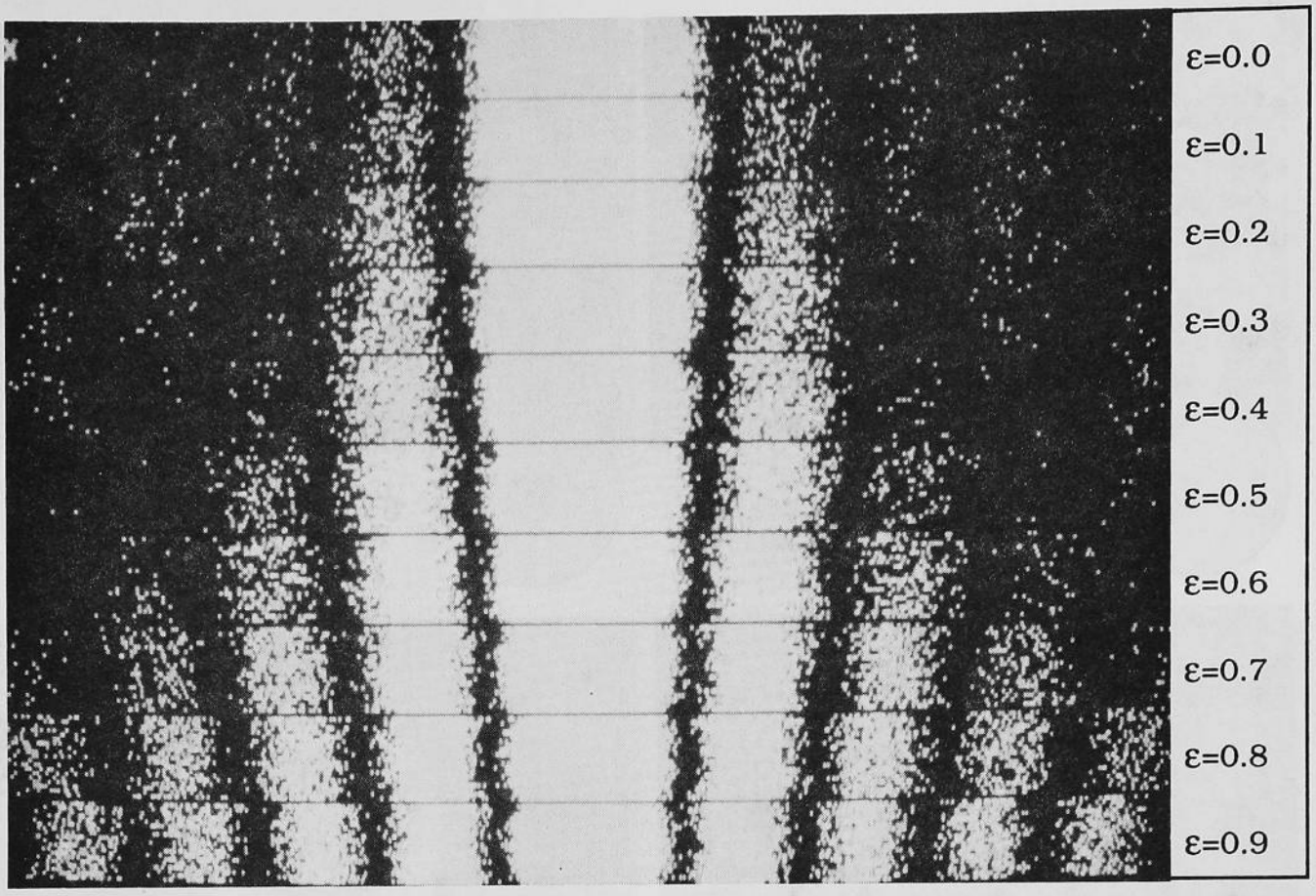
```
def fnairy(nu)
if nu<>0 then
  jterm=(2*fnbj1(nu)/nu)-eps*(2*fnbj1(eps*nu)/nu)
else
  jterm=1
epsterm=1/((1-eps*eps)*(1-eps*eps))
fnairy = epsterm*jterm*jterm
end def
```

where *nu* is the radial distance from the center of the Airy pattern and *eps* is the central obstruction. The functions fnbj0 and fnbj1 are the zero-order and first-order Bessel functions respectively. These are evaluated in a routine adopted from *Numerical Recipes in C* (Cambridge University Press, Cambridge, 1988).

The pixel illumination routine allows the user to specify a "gain" factor that is multiplied by the point spread function for the comparison with the random number. Detail that is too faint to show on the screen is thus brightened into visibility. For all Airy patterns presented in this article I used a gain of 10.

Results The Airy pattern of an unobstructed aperture, i.e., for epsilon equal to zero, consists of a bright central disk surrounded by a series of faint concentric rings. This is the classic Airy pattern illustrated in textbooks. Each ring is dimmer than the one inside it, and

These figures show how an obstruction changes the diffraction image. The top figure goes in steps of 0.1, and has a gain of 10; the bottom flows as smooth graduation from 0.0 to 1.0, and has a ring-enhancing gain of 100.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ε=0.3
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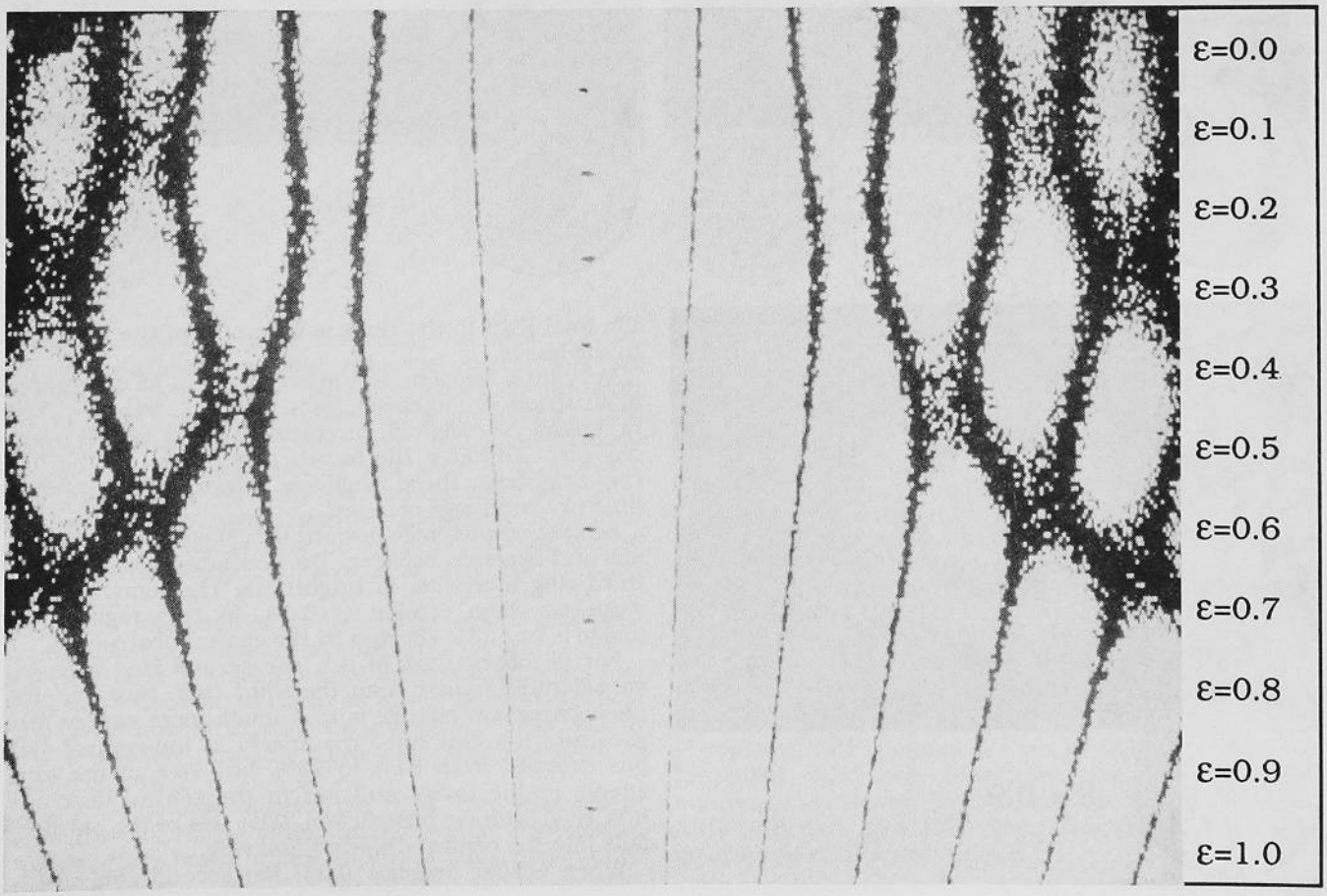
ε=0.9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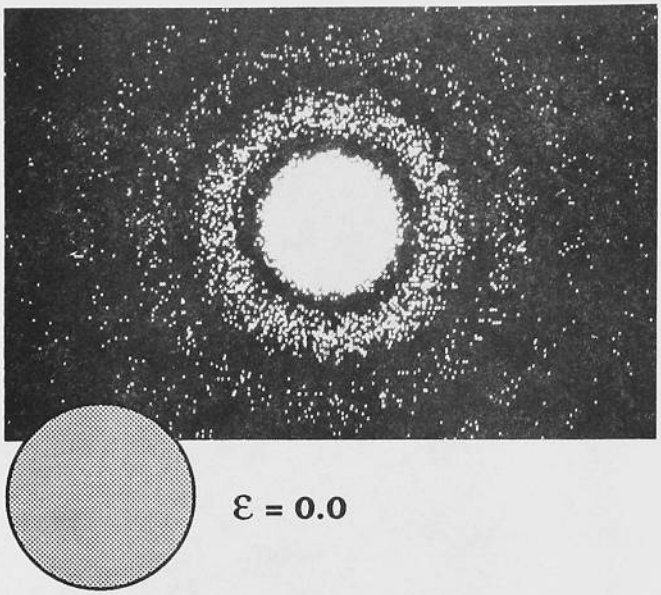

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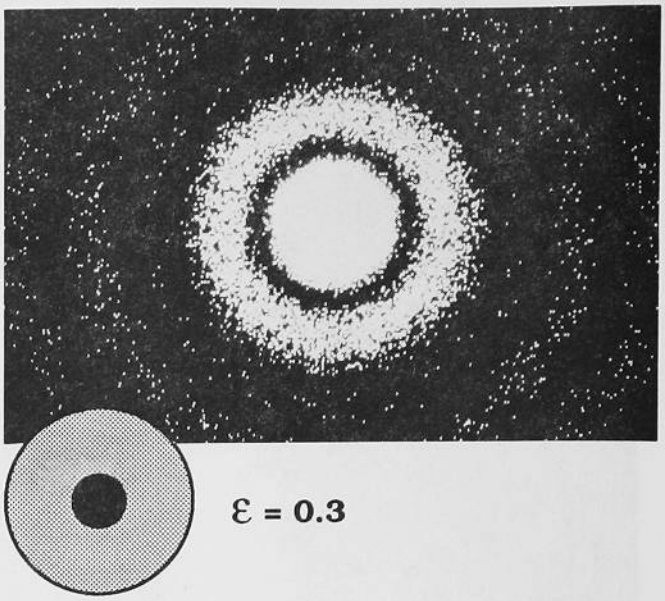

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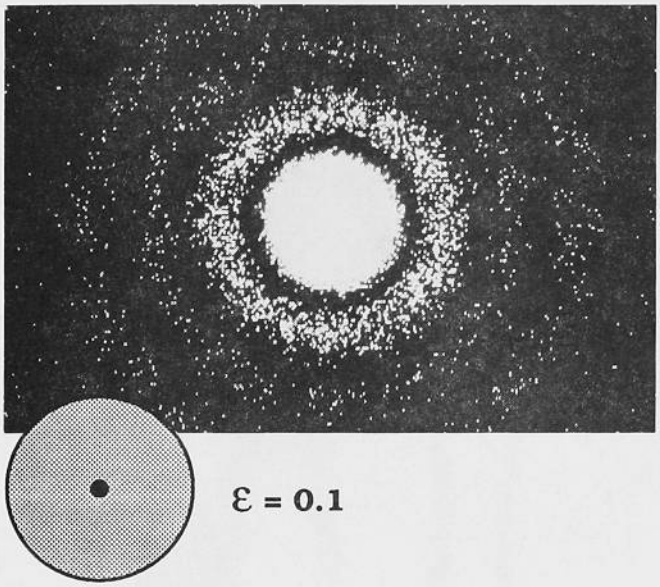

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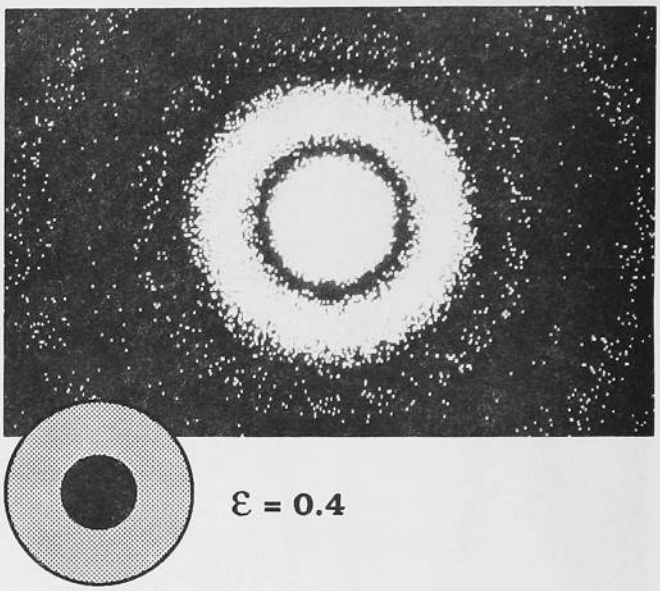

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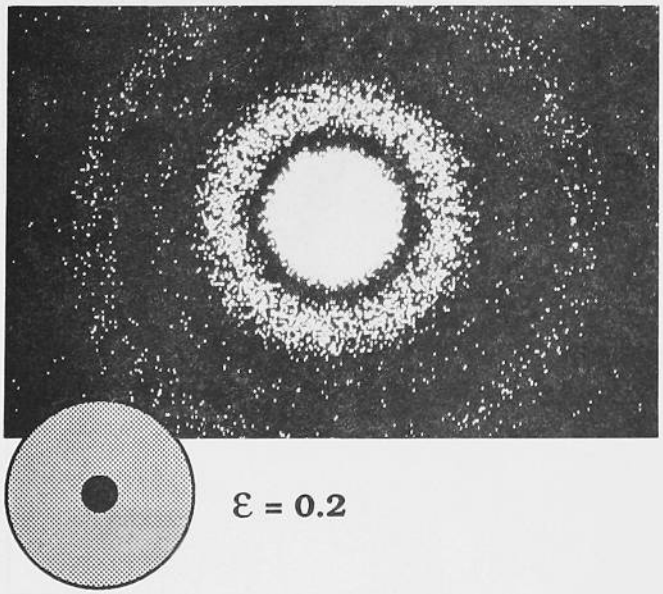


ε = 0.2

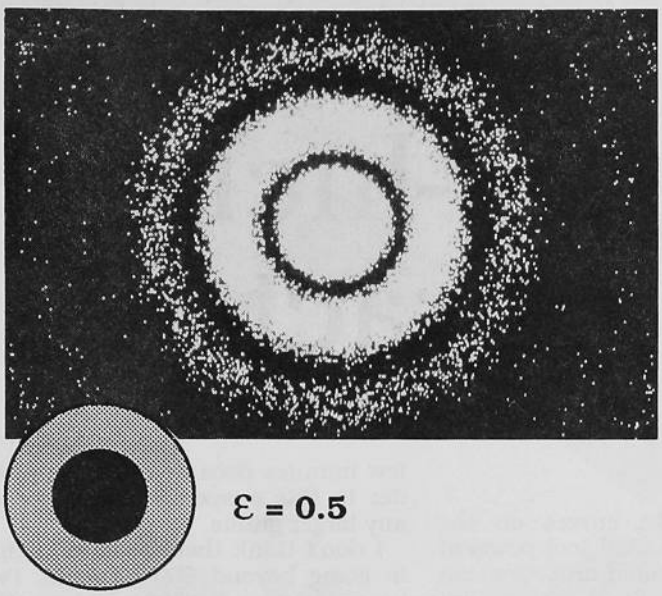
the total light in the rings is only 16% of the total light in the image.

Very little happens to the Airy pattern as the central obstruction is increased from 0 to 0.1. The first ring brightens very slightly, producing a slight loss in image contrast. Although the fourth ring dims and the fifth ring brightens, these rings are extremely faint and do little to alter image contrast.

As epsilon increases toward 0.2, the first ring brightens and becomes broader. The second ring dims as the third ring increases in brightness. The fourth all but vanishes when epsilon is 0.16. In this regime, the image is but little effected by the central obstruction.

For an obstruction of 0.2, the second ring becomes considerably fainter than the third ring. However, the most important change is that much more energy now goes into the first ring. The energy in the central disk has dropped from 84% to 76%, but 90% of the total energy in the image still lies in the central disk and first ring; with no obstruction, 91% lies of the starlight falls into the central disk and first ring.

When epsilon reaches 0.25, the second ring nearly



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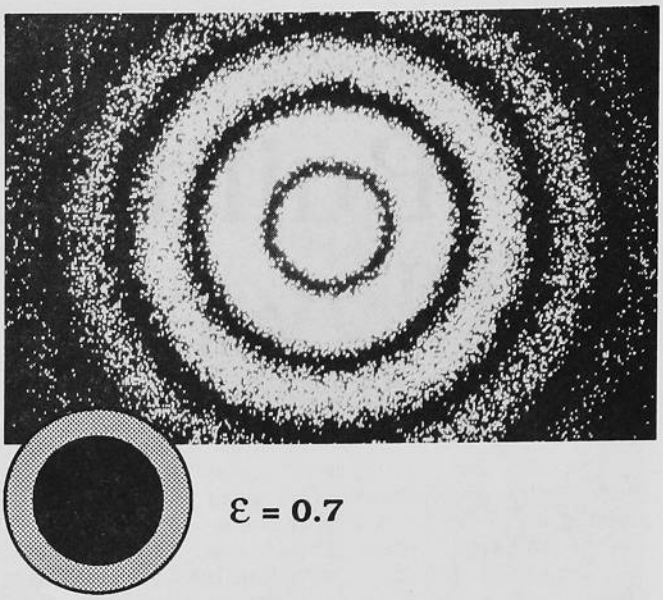

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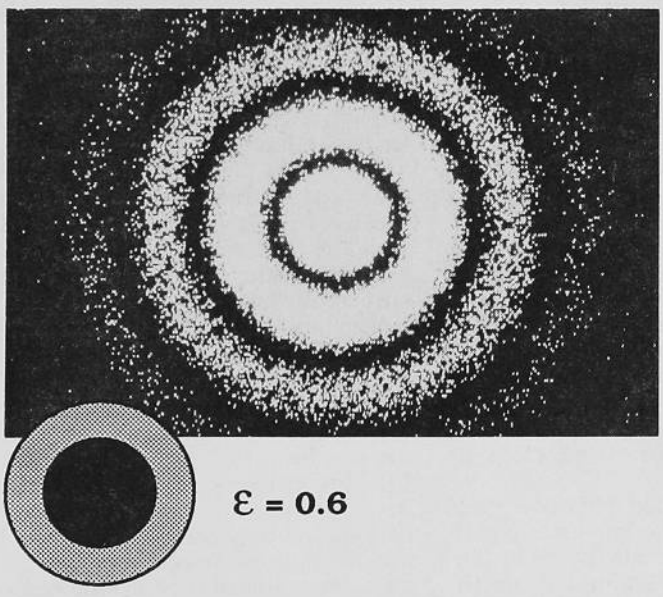

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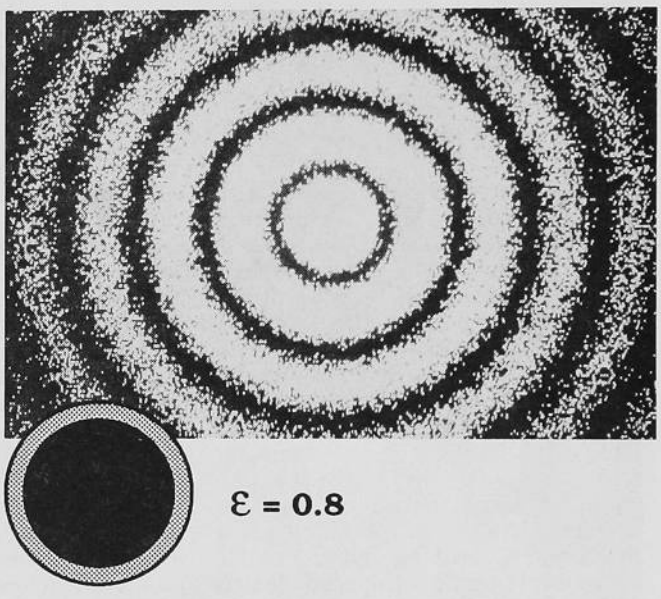


ε = 0.8

vanishes and the third ring becomes quite bright. Because obstructions near value of epsilon this are common in Newtonians, these telescopes do not show the "classic" Airy pattern of monotonically dimmer rings even when they are optically perfect. A perfect Newtonian with a 25% obstruction will show a moderately bright first ring, virtually no second ring, and faint third and fourth rings. Observers familiar with second-ring-less Newtonians may be surprised to see two or more delicate diffraction rings when they look through a refractor.

The first ring reaches its greatest prominence at epsilon of 0.33. Now 65% of the starlight falls into the central disk, and 24% of the total light falls into the first ring, more than three times as much as is in the first ring of an unobstructed aperture. At 0.33, the fourth ring is brighter than the third ring, which is brighter than the second.

For obstructions larger than 0.33, the second and more distant rings dominate the visual impression. Brighter rings begin to form in steady progression once epsilon passes 0.40. Cassegrain and Schmidt-Cassegrains perform well in this regime despite the considerable handicap of light diffracted into the rings.

By 0.50, the second ring is as bright as the first ring is in an unobstructed telescope. Such instruments may perform well for photography, but for high-power visual observing the resolving potential of the aperture is greatly reduced compared with the same aperture having a smaller obstruction. This does not mean that a large instrument with a large obstruction will not outperform a smaller instrument; but rather that a same-size instrument with smaller obstruction will form a cleaner central disk.

I have included epsilons up to 0.8 to show how the number and intensity of rings grow with increasing epsilon. Clearly such large obstructions are not practical for imaging tasks in astronomy.

Copies of this program are available by mailing me a formatted 5.25-inch 360-Kbyte floppy in a self-addressed, stamped diskette mailer. I will copy the AIRY.BAS and AIRY.EXE files onto the diskette and return it to you in your mailer.

— Richard Berry

Building a 4-Inch Plywood Refractor

The idea for making a telescope principally of plywood came from seeing a photo of a 3-inch refractor made by Larry Manuel. This had a square tube mounted altazimuth fashion on a tripod and followed in large part the design in *Build Your Own Telescope*. I ground and polished the objective; it is a 96mm f/15 Littrow design.

Design of the Objective

I used the 3 equal curves and a plane Littrow design featured in Andrew Sorenson's article in *Telescope Making #36*. I wanted a lens with a focal length of roughly 60 inches, giving a focal ratio of f/15 or thereabouts. The glasses which were produced by Chance Pilkington (now known as Pilkington Special Glass Ltd.) were their Hard Crown HC 518603 and Dense Flint 620364. Using these glasses one could, of course, design an objective corrected fully for coma; either a Fraunhofer contact type or for faster systems an airspaced design where R2 can equal R3. In neither of these aplanats would the last surface R4 be plane.

One advantage of using this HC/DF combination is the superiority of its color correction over that of a BSC/DF doublet. The secondary spectrum The secondary spectrum as a proportion of the focal length can be calculated from the equation:

$$\Delta f = (P_{Fd(C)}-P_{Fd(F)})/(V_1-V_2)$$

where $P_{Fd}=(N_F-N_d)/(N_F-N_C)$ for each glass, and V is the constringency of each glass. Secondary spectrum for the HC/DF combination is 0.000454, or 1 part in 2200 of the focal length. For the BSC/DF doublet, the corresponding figure is 0.000514, or 13 percent greater.

Optical Work

I generated the curves on the disks with a diamond tool powered by an ordinary bench drill. One can calculate the angle that the diamond tool makes with the blank or more readily the depth of sagitta which can be checked with inexpensive feeler gauges. Rather than cement the glass with pitch I made a ring into which the discs could be dropped and removed easily. Generating the three surfaces took only 15 or so minutes.

Grinding. I employed a machine and hands in combination to grind the lenses. The discs were supported by a ring so they could easily be interchanged. I ground both sides of the crown with the flint all the way through to the final 800 grade alumina (aluminum oxide) to keep all three curves as close as possible.

Smoothing started with 180 grade carbon to bring the curves to equality and to remove all traces of diamond scratches. I found it worthwhile to apply this abrasive and all finer grades with a brush, working a small amount of the slurry evenly over the surface. When I started work, I had shaken the powder roughly over the glass, but had found it impossible to make the surfaces match. Another aid in reducing fine grinding time is to eliminate any larger grains there might be by rubbing a batch of abrasive for a minute or so between two sheets of glass.

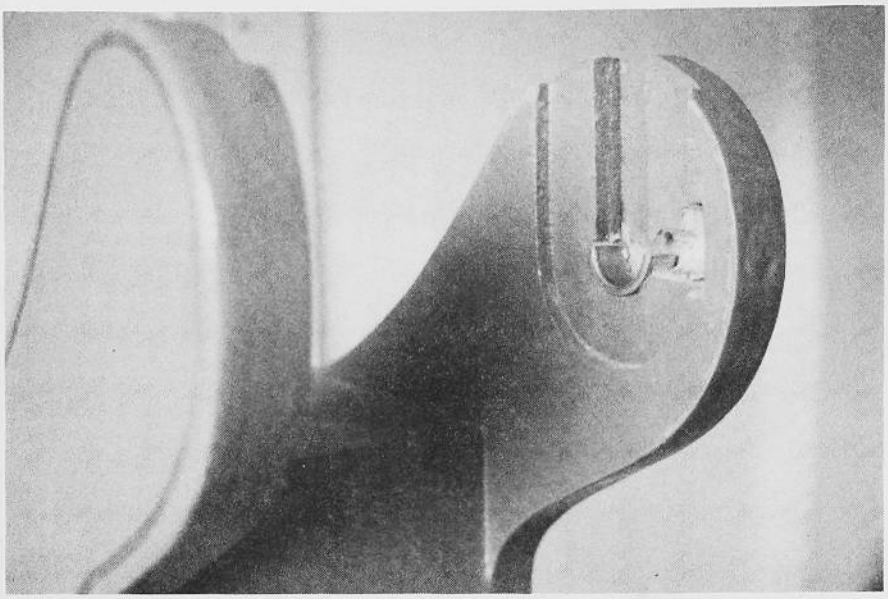
The powder I used wasn't very well graded and needed this treatment in the 180 and 280 sizes. The 400 carbon and 600 alumina seemed fine while the 800 alumina that I finished with was improved by being shaken in a water glass (sodium silicate) solution and then after being allowed to settle for a few minutes decanted off. The powder in this suspension was free of any larger grains.

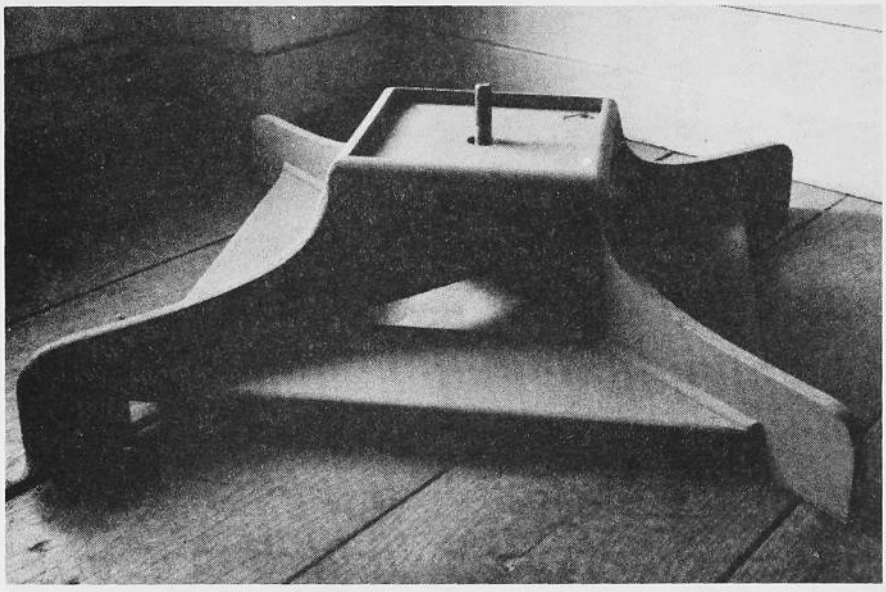
I don't think there is much point in going beyond 800 alumina. I've tried 1000 and 1200 grades with plain and facetted tools and taken every care in ensuring the cleanliness of powder and equipment, have beveled all edges, have made sure that temperatures have equalized and have never arrived at the point where I could be confident that the surfaces would remain scratch free. It's not worth it. If one uses the flint to grind the two crown surfaces, one must be especially sure about avoiding scratches.

My smoothing method was for the lower element to rotate at a slowish rate on the turntable and grind it with the upper using a continuous circular sweeping stroke keeping the overhang to between 1/4- and 1/2 inch. Every few seconds the upper glass is allowed to rotate a little slipping between one's fingers. If this sweeping action is slow and the abrasive is distributed evenly before grinding and the overhang is kept small, there is little danger of turning the edge or losing contact at the center. This technique is twice as fast as the center over center push and pull method. I used it until the last abrasive stage when I connected up the upper element to the machine's arm.

All surfaces of the objective were ground with the same grade of abrasive before they and the machine, etc., were thoroughly washed, fresh papers were laid down and the process started again with the next abrasive size.

David Cartwright's 4-inch refractor is mounted on a handsome alt-azimuth pier mounting. Behind is Clifford castle, built in 1066, destroyed in 1402.





Altitude bearing is an oilite bushing embedded in the wooden fork. The base is a solid cross made of plywood; the plywood pier bolts to it.

The lower piece of glass was constantly changing to ensure that the curves remained on target and that astigmatism, especially in the final stages of firing, wasn't being ground in because of unevenness of support. One can't take too many pains about this, especially when using a machine where all processes tend to be speeded up.

One must be finicky about maintaining bevels on all edges. During the last stages I smoothed the bevel by grinding the edge against a pane of glass using 400 or 600 grit.

Wedging. The diamond drilling naturally tends to reduce wedge to 0.002 to 0.004 inches. This can be tackled with 180 or 280 carbon quickly on the machine. The upper element is held stationary with most pressure on the high side while the lower rotates. When this wedge is less than say 0.0015 inches, the other glass is treated in the same way. The final correction is accomplished with 400 grade carborundum. I aimed for 0.00025 inches, though twice that would probably be acceptable in a lens of this size. After any work removing wedge the glasses should be given a few ordinary wets to remove any astigmatic unevenness and rechecked. The wedge of the glasses didn't seem to wander much during the 600 and 800 stages.

For this testing each glass had a mark scratched on its side, the crown with an arrow to distinguish each surface, and was measured on a jig as in drawing. This was knocked up in a few minutes from wood and screws and proved reliably accurate and convenient. I used nylon supports and stops for the lenses, but metal supports could be covered with tape to guard against scratches.

The plane surface, R4, was produced by grinding against two other discs, each being worked against each other in rotation. During this time the concave R3 was in contact with the hard aluminum ring and because I hadn't ground a 1mm flat edge suffered some small chips being flaked off. A pity, although they wouldn't intrude into the clear aperture of the lens.

Optical glasses tend to require more time per stage of fine grinding than float glass or Pyrex. I suppose greater speed of glass removal doesn't make up for the greater depth of pits produced in these more brittle glasses. Hence the importance of having well graded abrasives. I followed the progress of pit removal with two eyepieces, a 25mm Kellner for general appearance and a 5mm Ramsden for closeups of problem pits. I held the eye-lens nearest the glass, which was held up to a bulb.

Polishing. Polishing was done on a machine. I found it necessary to use a high spindle speed to achieve a reasonable rate of polishing. With too low a speed the glass refused to be polished however much weight was placed on the arm. The machine I made was based on that described by Warren S. Fillmore in *Advanced Telescope Making Techniques, Volume 2.* The polishing (or grinding) action depends on the difference in rate of rotation of the upper and lower elements. It has a vertical spindle with an adjustable arm that can oscillate or be fixed and which controls the eccentricity of the upper component with respect to the turntable.

I disconnected the throw arm and fixed it so that the upper element was offset relative to the lower by around an inch. This did quite a good job of polishing if polisher and glass changed place occasionally. When glass was in lower position it was necessary to fit a rubber ring around the edge of the disc; the resulting reservoir preventing polish being lost over the side.

As regards this type of machine it's important to have the drive bar

engage the upper element as low as possible and keep the friction between the end of the bar and its socket as small as possible. I had neglected both these points on making the machine at first with the result that polisher and glass plucked at one another and polishing was impossible.

This objective was one of three similar doublets I made as a batch on one of the other Flint concaves I managed to polish in astigmatism despite taking precautions I thought. It may be that it's worth pitching the glasses into their holders. I'm sure the chances of irregular polishing increases with the speed of polishing. There were never problems of this kind with slower hand polishing on a barrel.

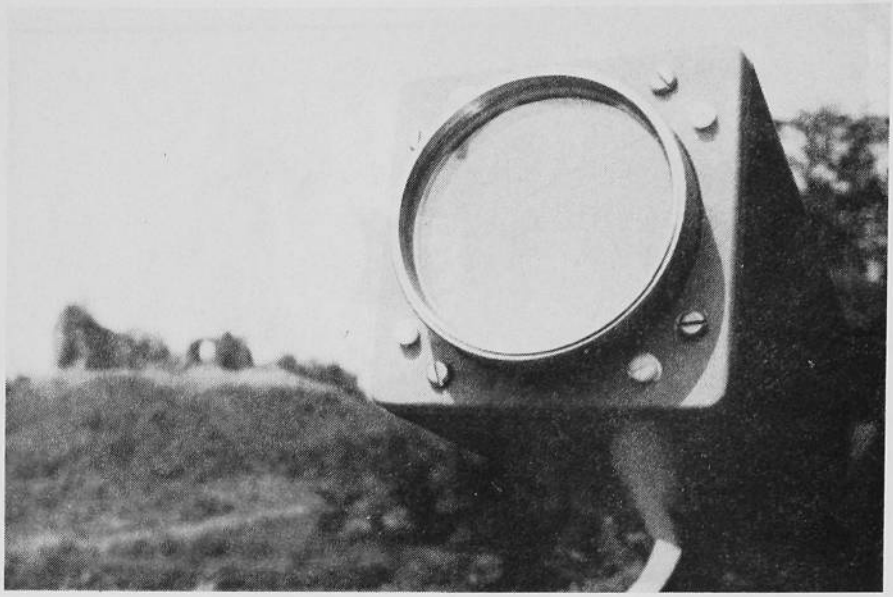
Each surface was given three hours of polishing as described followed by an hour at a slower spindle rate with the upper arm oscillating to and fro. This smoothed out the zones to a great extent but didn't entirely remove them. This machine polishing was nearly a continuous process. As one surface was being polished another was being cold pressed. The laps were composed of circular facets made by a rubber mat stencil.

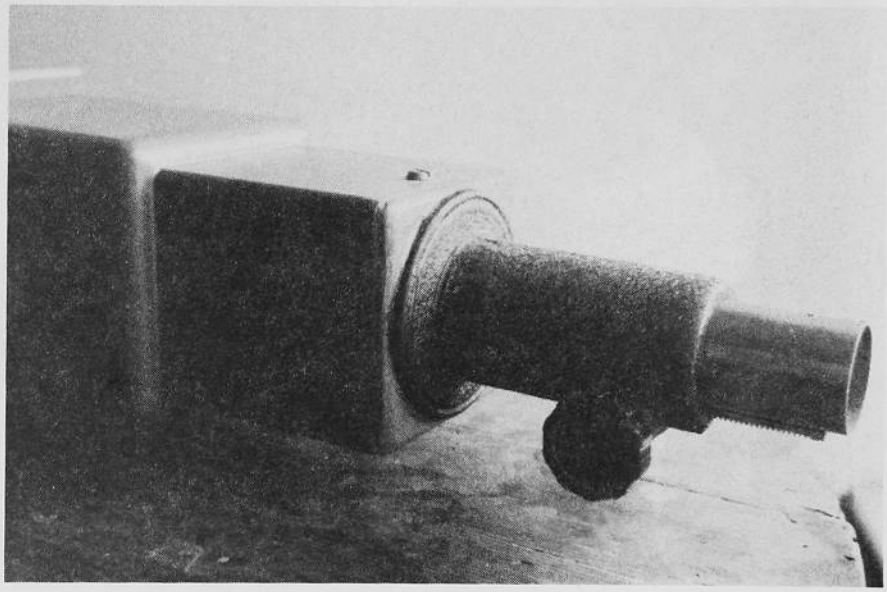
Microfacets made by plastic netting speeded up the work. The pitch was of fine medium hardness supported by glass discs and every hour or so was softened under an electric grill in order for the lap to be remade with the mat and netting.

Four hours or so of work resulted in a pretty good polish. There were a few pits around the margin of each surface, but not many, and I didn't feel it was worth the extra hours each surface would need to eliminate them entirely.

I found that both the fixed and oscillating arm method of polishing left all surfaces free or nearly so of turned-down edge. But the greatest advantage apart from its speed was the absence of any tendency to scratch. I used the same laps for all three objectives. As they became older a few sleeks appeared, interestingly where the polishing action and therefore the pressure was least.

Throughout the process of grinding and polishing I hadn't troubled to test for curvature, and was punished for my casualness to find that the focal length had moved to 65 inches. By this time I had nearly finished the tube and was lucky to find I could just accommodate the extra inches by extending the narrow section of the tube.



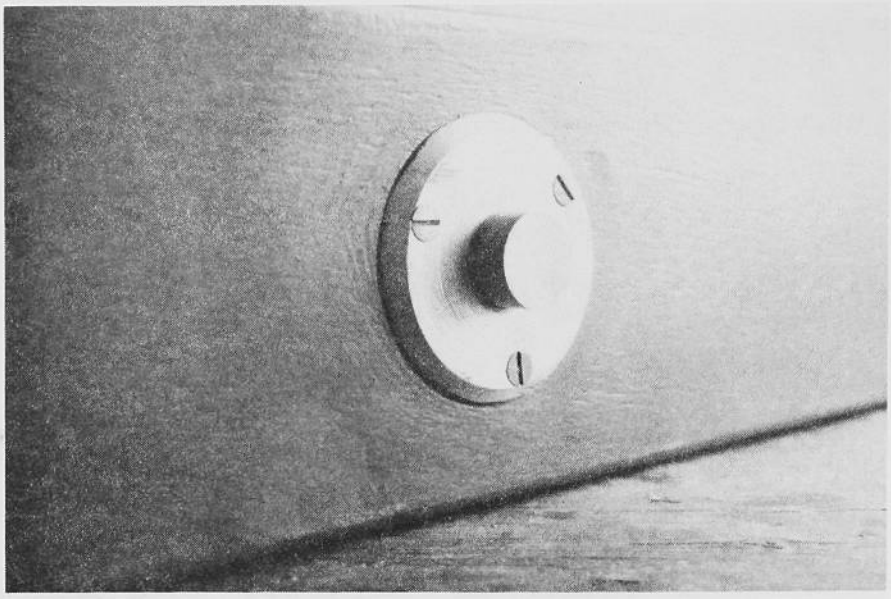


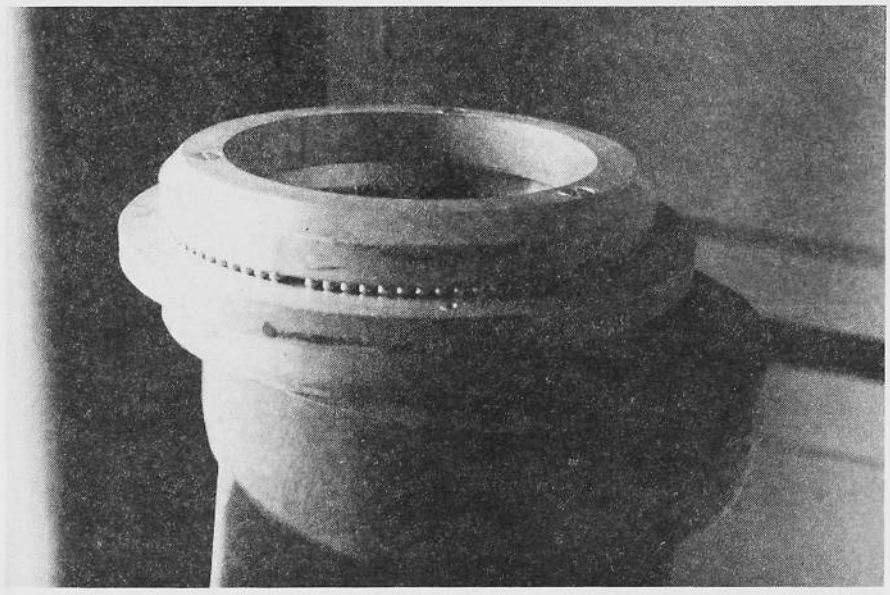
Mounted in a turned brass cell, the objective is cemented to a plywood alignment plate. The end of the tube is stepped off for dramatic effect.

The color correction was tested by interference using a neon glow bulb. When viewing the fringes formed between the two concave surfaces and the concave the crown acts as a collimator. When testing the plane surface, a magnifying glass must be placed above the flint to see the whole surface. This showed that there was a total error of curvature of 20 waves on the flint relative to the crown, which isn't too bad but 10 waves would have been better. R2 shouldn't correspond with R3 too closely as there is the possibility of ghost reflections if the glasses are airspaced and are not antireflection coated.

When checking figure in the four surfaces by interference any zones present might only show up as slight blips on the fringes. It would be a mistake to think that because the contour of a surface is within a few millionths of a perfect sphere one has a good optical surface. That slight blip 3 millionth of an inch high might cause a wave front error at the image of a wave or more if the zone was narrow enough. One should follow interference testing with a knife-edge Foucault test.

This is as far as the optical work has gone, removal of zones having to wait for building renovation work to be completed on my cottage.





Metal bearings appealed to Mr. Cartwright's aesthetic sense. He favors the use of traditional materials in an telescope of traditional appearance.

Another advantage that having the machine gives is the speed and control in removing zones. I expect to slowly run the lap face up on the turntable having cold pressed raised rings corresponding to the high zones of the lens which is hand held.

Radius Errors. Each surface error of curvature or the sum of surface errors can be thought of as adding a simple lens to the optical train. The resulting chromaticity will be harmless when the focal length of this lens is such that the diameter of its Airy disk equals or exceeds the diameter of its chromatic blur. For any simple lens this is given by: $d = D/2V$, where V is the constringency of the glass.

If we consider deviations of the surface curvatures in terms of flint glass with a V figure of 36.4, the focal length of the imaginary lens, then $F \geq 10D^2$. In my case, F is 100 meters.

If the simple lens is considered to have one surface curved and the other plane, then because the radius of curvature is twice the focal length, it is 200 meters, and the sagitta is 0.00625 millimeters, or 25 waves maximum allowable error of curvature. For crown glass with a V figure of 60.4, the allowance can be doubled to 50. Because the doublet is only approximately achromatic, these tolerances can be relaxed somewhat without harm.

A stringent tolerance would be where the circle of least confusion resulting from these errors of curvature would be no larger than the Airy disk of the objective. For a 4-inch objective this is 1.1 arcseconds, which corresponds to a maximum curvature error of 20 waves. Because of the imperfect color correction of a 4-inch f/15 doublet, this tolerance could no doubt be relaxed somewhat without loss of performance.

Knife-Edge Testing. It's a great help to be able to test by autocollimation if a flat is available. One needn't put the lenses in a cell as everything can be squared on easily by eye. The glasses are protected by pieces of tape and testing is as convenient as that of a spherical mirror.

A flat can be made from 10mm float glass using the three plate method. All three are polished, two of them just sufficiently to allow interference flanges to form clearly, and the third more fully but without too much concern for pits and scratches; or for curvature of a few waves. Figure one flat as well as possible testing against the other two. If this flat is considerably larger than the objective and if they are off-centered with each other, one can see where any zones belong. Even if the flat isn't perfect, one should be able to use it to bring the object glass to the point where it can be checked against a star or a sufficiently distant light source.

Mechanical Construction

Having seen and been impressed by photos of telescopes with square tubes made by Larry Manuel and in *Build Your Own Telescope*, I decided to do the same and also continue the square cross section down to the ground through a pier.

Because the clear aperture of the objective would be only 96mm, I chose 3.5mm exterior ply for the walls of the tube reinforced with panels of 6mm ply, where it would receive screws for altitude bearings and balance supports. The seven or eight baffles were of 6mm ply and served to strengthen the tube as well as reduce contrast. The apertures of these baffles were cut at 45 degrees so as to present the smallest reflecting surface.

The lengths of wood that joined the four sides of the tube at their corners were radiused and rebated to accept the plywood panels.

Whilst this added a little to the expense of the tube and pier, it added much to the appearance of the instrument.

A waterproof resin glue, sold here under the name "Cascamite," was used throughout without any screws except for some large brass ones which reinforced the cradle. The carpentry isn't especially difficult, but fussing over the many pieces that went to make up the telescope was quite time consuming.

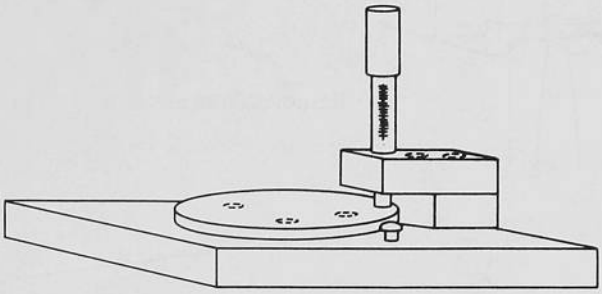
Three sides of the tube were cemented together and after being trussed up with twine were left overnight to set the inner surfaces of the tube, and the fourth side was painted mat black and left for a few days to dry before it and the smaller extension tube were fixed together.

The Cradle. Built up from different thicknesses of ply, the cradle is cut out where necessary to accommodate both bearings and to form a well into which was eventually poured a counterbalance of molten lead. A jigsaw was used to cut the curved parts of the cradle which, after gluing together, was rasped and sanded to the correct shape. After the 10 to 12 pounds of lead had been poured the cradle was treated with filler and given several coats of paint.

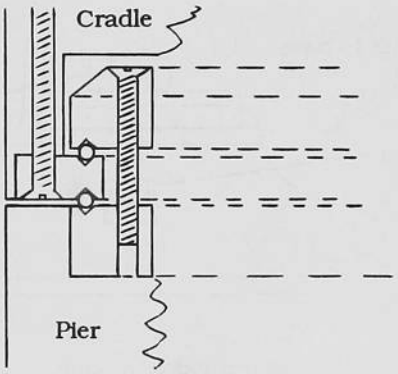
Two semicircular bush bearings of "oilite" bronze were fixed in to receive the altitude brass stubs. To make them coaxial two pieces of dowel 1/2-inch and 1/4-inch diameter were glued together and were used to position the bushes whilst their glue was setting. The telescope tube was then supported in position, and the aluminium flanges of each aH bearing glued to the tube before brass machine screws and nuts were placed to receive them. A rough and ready method of doing this important job but it seemed to work well.

The Pier. I made the pier in a similar way to the tube using 1/4-inch ply for the sides, 1-inch square section lengths and 1/4-inch quarter round moldings down the corners and a mixture of 1/4-inch and 3/4-inch ply to form the cross pieces.

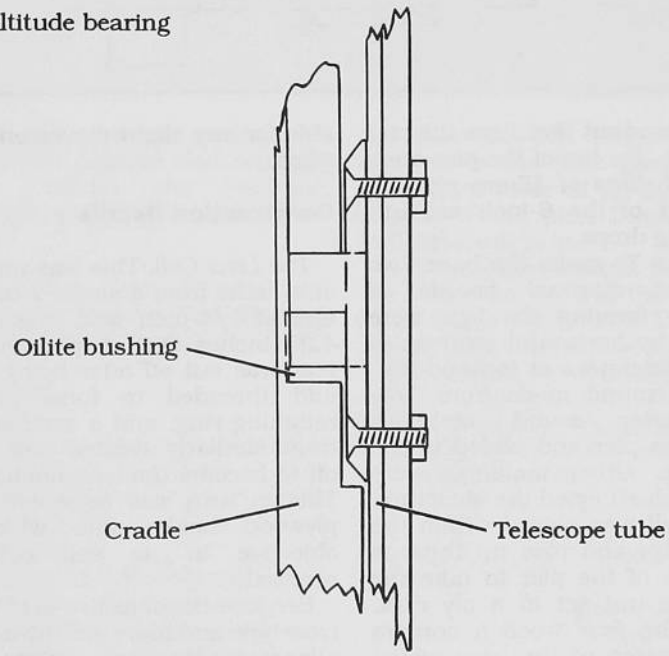
The surrounds for the two doors were made from left over rebated moldings whilst the door was made up from 3.5mm ply and fixed with small brass hinges. The base of the upper compartment is made from 15mm ply on 6mm plywood. The 15mm ply has 1.375-inch and 1.125-inch cores removed to take eyepieces and other useful things. The lower door gives access to a sin-

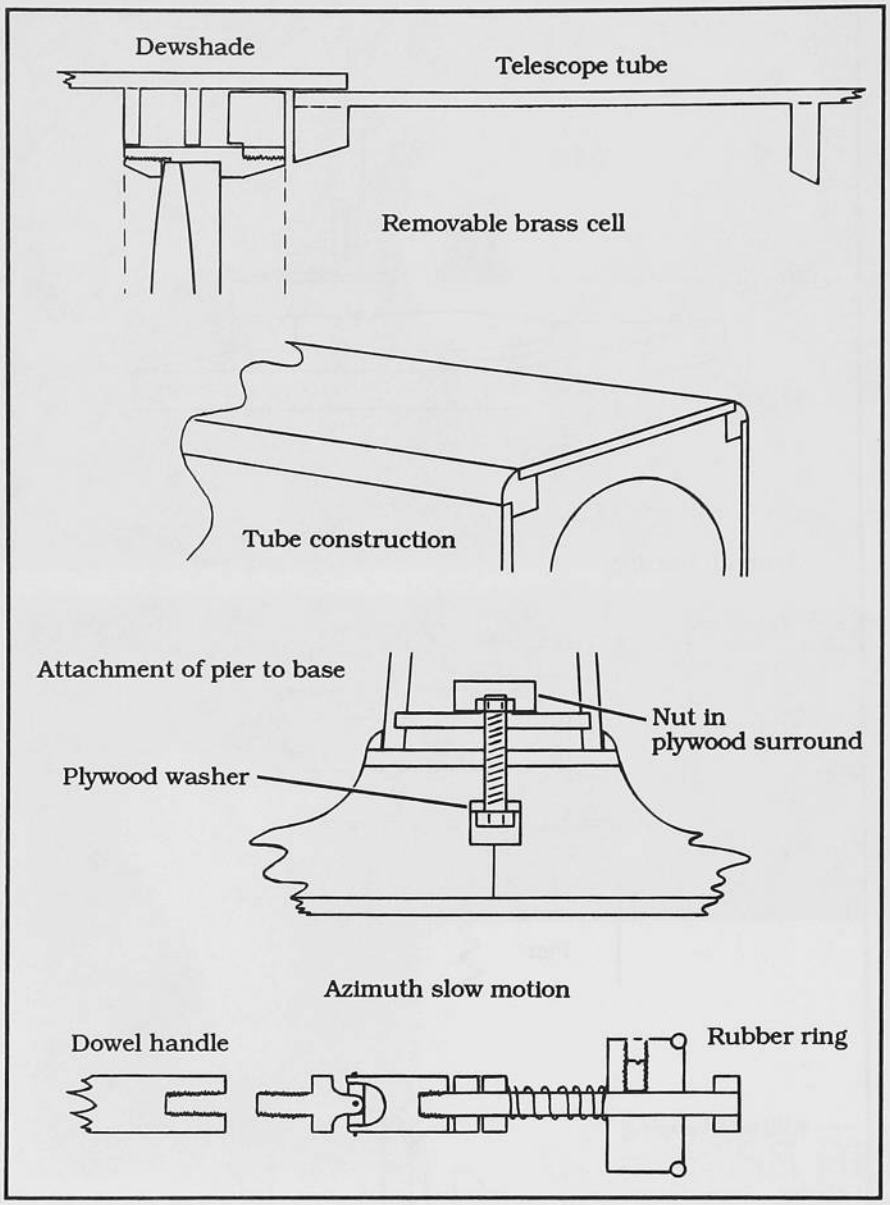


Azimuth bearing



Altitude bearing





gle large handnut that fixes the pier to the base. On top of the pier are a number of discs of 15mm ply into which part of the 6-inch azimuth ball bearing drops.

The Base. To make the base, two interlocking diagonal boards of 15mm ply forming the legs were reinforced by horizontal sections of the same thickness at top and bottom. A surround made from 3/4-inch quarter round moldings received the pier and added to the appearance. Other moldings were added which stiffened the structure. A heavy bolt was placed within the diagonal legs and rose up through the bottom of the pier to take the handnut, a nut set in a ply disk. Three of the four wooden corners rest on the top of the base whilst the fourth corner has a bolt adjustable for any slight movement in the wood.

Construction Details

The Lens Cell. This was machined on a lathe from a single 2-inch section of 1/4-inch wall brass piping 4.25 inches O.D. A portion of the rear was cut off after being turned and threaded to form the lens retaining ring, and a section of the front similarly treated and turned off to become the lens holding ring. This in turn was cemented into a plywood holder into which the objective in its cell could be screwed.

Because the objective is of the Littrow type and more sensitive to misalignment than an aplanat, and because the wooden tube might warp slightly and because its good practice anyway, I put in 4 pairs of push-pull collimating screws. Three pairs are sufficient but I had space available only at the corners. The nylon push and pull brass screws travel through 1/4-inch long sections of 1/2-inch brass rod cemented into the 1/2-inch thick plywood square that holds the cell.

Behind this plywood square lies another of the same thickness that forms the end of the telescope tube and into which 4 matching pairs of 1/2-inch brass rod are glued. The machine screws are 5mm O.D. metric thread and the sections of brass rod were drilled on the lathe with a 5mm or a 4.2mm bit and then tapped or left solid according to their function. In this way, the lens can be removed from the telescope while within its cell without affecting collimation.

Bearings. The altitude bearings are brass studs 1-inch diameter 1/2-inch long in Oilite bronze half bushes. The brass studs started off 1-1/16 inches diameter and had molten aluminum cast around them in sand to form 3 inches wide 1/4-inch thick flanges. The whole was then machined smooth and to the right size on the lathe including a 45° chamfer around the edge of one flange to take a rubber slow motion drive. Three countersunk brass screws fix each flange to the telescope tube.

The azimuth bearing is a 6-inch double ball race, composed of an aluminum ring 7 inches O.D. and 5.5 inches I.D. sandwiched between two aluminum rings each 6 inches O.D. and 4.5 inches I.D. Four shallow grooves were cut to contain a couple of hundred 3/16-inch steel balls. The outer section of the middle ring connects with the cradle whilst the upper and lower sections, which are screwed together, rest on the top of the pier. The whole bearing is contained and hidden within the cradle and pier top. The upper edge of the top ring is chamfered like that of the altitude bearing to receive a slow motion wheel.

Only two-thirds or so of the possible number of steel balls are used; when more are used they tend to bind with each other. Aluminum is probably a poor material to make a ball bearing from but at least it's soft enough for irregularities to be worn down quickly. In practice this bearing performs beautifully smoothly. I made it this way because I happened to have the aluminum which was to have been

made into patterns. In a simpler alternative, shown in the drawings, the counterbalanced weight of the cradle and scope is supported by one central steel ball. A steadying action is exerted by three nylon screws with or without steel balls running in a groove.

Slow Motions. Slow motion might be imparted to each axis by a rubber ring on a wooden or brass bobbin. This is forced by a spring against the chamfer and is driven by dowel handles via brass universal joints. All brass parts were made from 5mm and 12.5mm rod. The slow motion devices are contained within the cradle and rotate within small brass bushes.

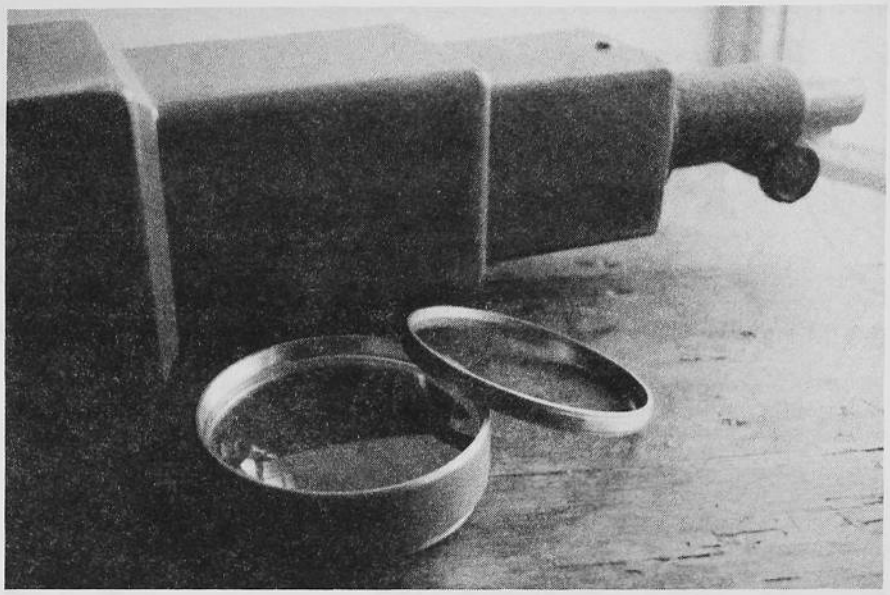
When the telescope is being swung to find an object, both slow motions can be disconnected by pulling against their springs and perhaps held by a clip.

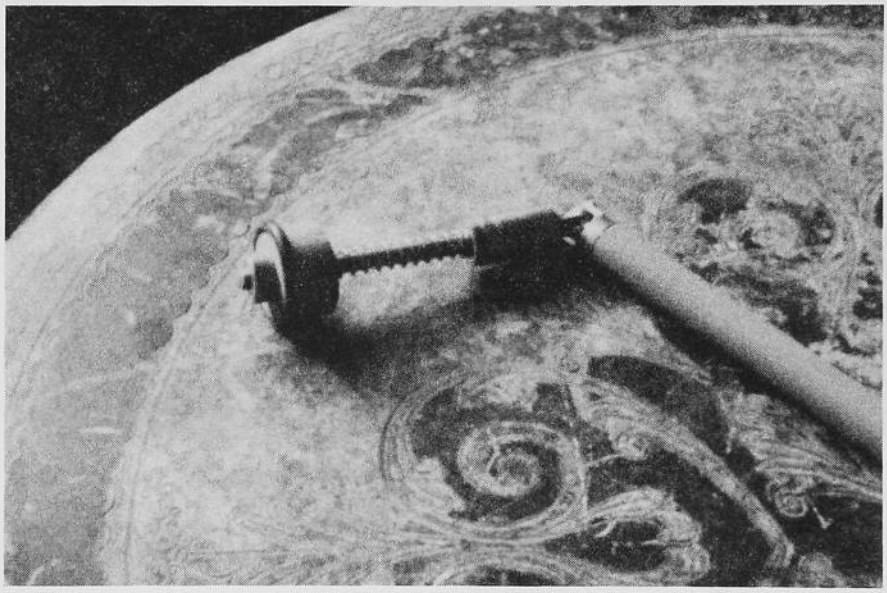
Counterweights. Two lead weights 1.5 inches in outside diameter were cast in cardboard tubes around 1/2-inch dowels. The lighter of these two will run on a dowel beyond the cradle and the other between the eyepiece and cradle. It would have been better to have cast the lead around 5/8-inch dowel to allow room for lining the insides of the weights with cloth to avoid scratches. The sides of the weights were drilled and tapped to receive securing screws.

Dewshade. Made the same way as the main tube but using 3.5mm ply throughout, the dewshade slips over the main tube. Two baffles slide over the lens cell. An improvement to ensure that the dewshade snaps crisply into position would be to glue some small magnets onto one end of the cap and have them engage adjustable steel screwheads on the tube end. One can buy flexible plastic strip that contains magnetic material which can be cut up into 1/4-inch squares or whatever. These magnets would remove any tendency to flop rather than support the entire weight of the dewshade.

Focuser. The focuser I selected is a commercial rack and pinion unit sold by Broadhurst, Clarkson & Fuller. It is cemented to a block of plywood which is fixed to the telescope tube with brass screws. The focus travel is sufficient to accomodate all the eyepieces I plan to use.

Finder Telescope. A finder was made from one objective, eyepiece and one prism out of a secondhand pair of 7x50 binoculars in plywood tube. The finder is mounted piggy-back on tube, but it was not installed when I took the pictures that appear with this story.





Spring-loaded slow-motion controls press against altitude and azimuth bearings. Below: the objective awaits final assembly into its cell.

Performance

As to whether this approach is a good one, I think the telescope has turned out handsome apart from some small details. It was laborious but didn't require a great deal of skill -- it was my first carpentry job. It's fairly rigid, vibrations damping down in a couple of seconds if knocked. Most of what vibrations there are stem, I think, from the fact that the bolt which connects the pier to the base goes through one 15mm piece of plywood at the bottom of the pier. Doubling that thickness will help.

Perhaps there should be individual bolts near each of the four corners but less convenient. Longer telescope tubes should be made from thicker ply as there is slight vibration in my one. The telescope breaks down for transport, but it's somewhat more awkward probably than one mounted on a tripod. Because it has four feet, it need more care with setting on the ground, although it seems quite stable.

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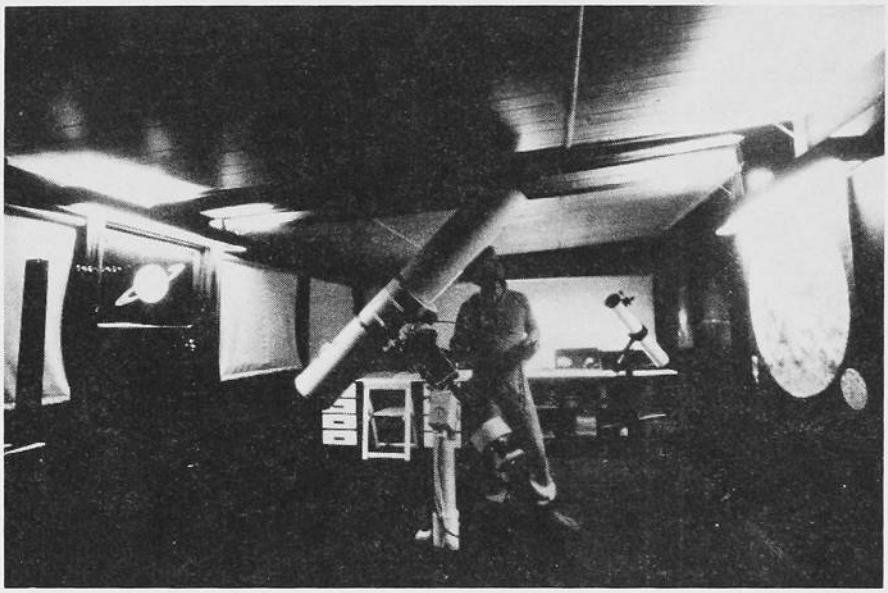
Split Roll-Off-Roof Observatories



The author in his observatory. Note the ample space he has for moving around, built-in shelves and cabinets, charts, and subdued lighting.

Several years ago I decided to build an observatory in order to eliminate problems I experienced observing with telescopes out of doors. Although I initially intended to construct a conventional dome type observatory, after using amateur observatories with domes it became obvious that while domes offer distinct advantages for large professional telescopes, they create problems when scaled down to suit the requirements of the amateur astronomer. The other common observatory design — the roll-off roof — offers too little protection from wind and dew.

Because I am interested in architecture and interior design, I decided to create an observatory more suited to my needs as an amateur astronomer. For this, I chose a design featuring a dual motion, multiple function, east-west split roll-off roof supported by a conventional building.

This article discusses several variations of this design and highlight its simple construction and low cost. I will cover planning an observatory for comfort, using the building during the day, protecting the observer from the elements, tracking objects, reducing thermal problems, practical interior decorating, the correct use of lighting, aesthetic exteriors for an observatory structure, placement of an observatory, auxiliary amenities, and planning for future development.

Initial Decisions After becoming interested in astronomy, most amateurs purchase or build a telescope and commence observing — usually from their backyards. Few amateurs need to be reminded of the recurring frustrations of setting up, packing away, dew, wind, mosquitoes, neighboring house lights, and a general lack of conveniences when observing out in the open. Serious observers soon contemplate the construction of an observatory to overcome these problems.

Initial decisions are: Should I build an observatory in the suburbs or look for a country sites? Can I build it myself? Which design would be the best for my needs? How can I encourage my wife's or parents' approval? How can I stop it from looking like an outhouse without spending heavily? Will it have any resale value?

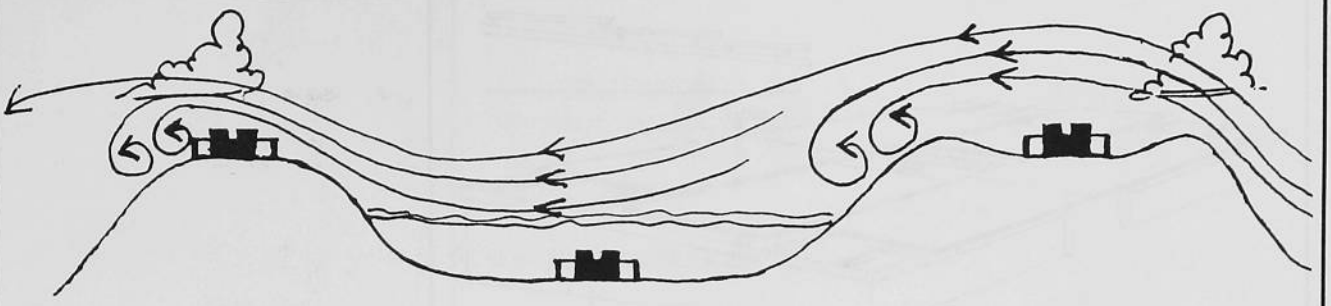
These are all important considerations when designing a practical observatory. It is the aim of this paper to suggest alternatives to the more conventional roll-off-roof observatory design in the hope that a more functional design may be achieved within a modest budget.

The Site After making a decision to build an observatory, the first thing to be considered is the site. II cannot stress to strongly that the more convenient the site, the more likely it is to be used. A convenient backyard site that does not suffer from intolerable light pollution will invariably receive far more use than a darker but more distant country site.

The advantages of being able to pop into a backyard observatory for short but frequent observing sessions should not be underestimated when comparing it with the bother incurred in gathering gear and driving into the country. If the sky becomes overcast white you at at home, you can carry on with another interest. In contrast, cloudy skies in the country mean the waste of a time-consuming and costly trip.

Country observing sessions tend to be long (and therefore somewhat tedious) to make the expedition worthwhile.

If you are contemplating the building of an observatory in a sub-



Poor
Hill attracts turbulence and cloud if over 300 meters high

Fair
Protected lowlands are steady but likely to suffer from smog

Good
Plateau—more likely to be both clear and steady.

urban area, be careful to anticipate future development of the region that may eventually render the site astronomically useless for observing all but the brightest of objects. If the suburb is young, you can expect a dramatic increase in street and commercial lighting. Check to see how close proposed shopping centers. sports areas, industrial estates, etc. will be when constructed. Also allow for the rapid growth of neighboring trees.

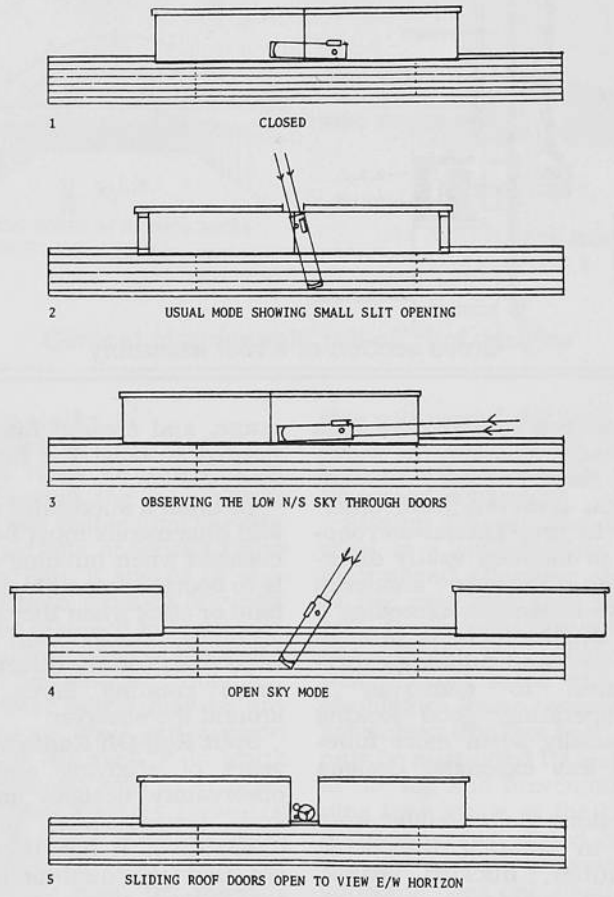
If deep sky photography or photometry is your primary interest, then a country site is virtually a prerequisite for excellent results. Anyone planning a country observatory will require a substantial budget. Not only will land need to be purchased, but some form of accommodation is usually required near the observatory if one is to be comfortable.

Remember that while mountains are preferred, they may attract cloud cover. When searching for a site, check the type of flora. It will help you to roughly gauge the rainfall in the area. Obviously, rain forest does not offer a desirable ratio of clear to cloudy nights. If you can, build in the rain shadow of a mountain where the land has that typically dry appearance. If you are purchasing land for a possible observatory remember that sites at the top of a hill that fall away on most sides suffer frequently from turbulence. A protected bowl-like plateau situation is best.

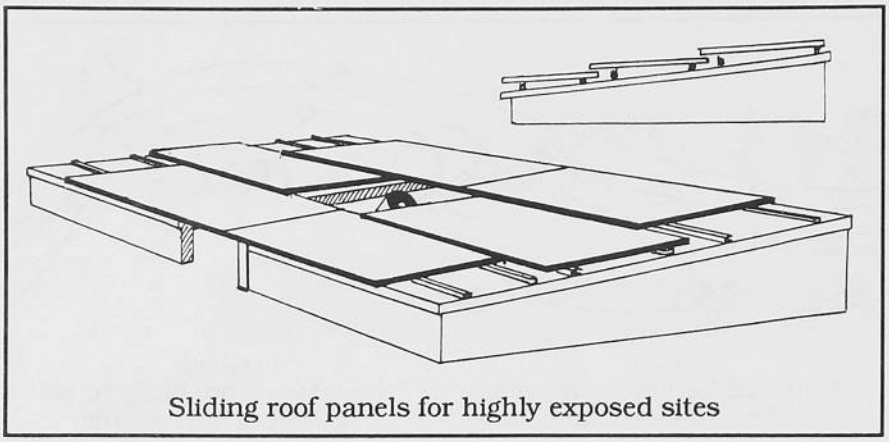
If you must build in a place with light pollution, it is more tolerable for southern hemisphere observers if the source of light is in the south provided, of course, that the pollution does not extend above the South Celestial Pole. (The reverse holds in the Northern Hemisphere – put your pollution in the north.) This is because objects low in the sky will rotate around the pole and into darker sky. Similar solutions are possible for pollution toward the east and west but not so for the low northern sky.

To escape light pollution from a major city such as Brisbane, the observatory would be best situated no closer than 100 km. Failing a severe energy crisis, light pollution is not likely to go away even though its present growth rate may be retarded in the future with the introduction of more practical lighting standards.

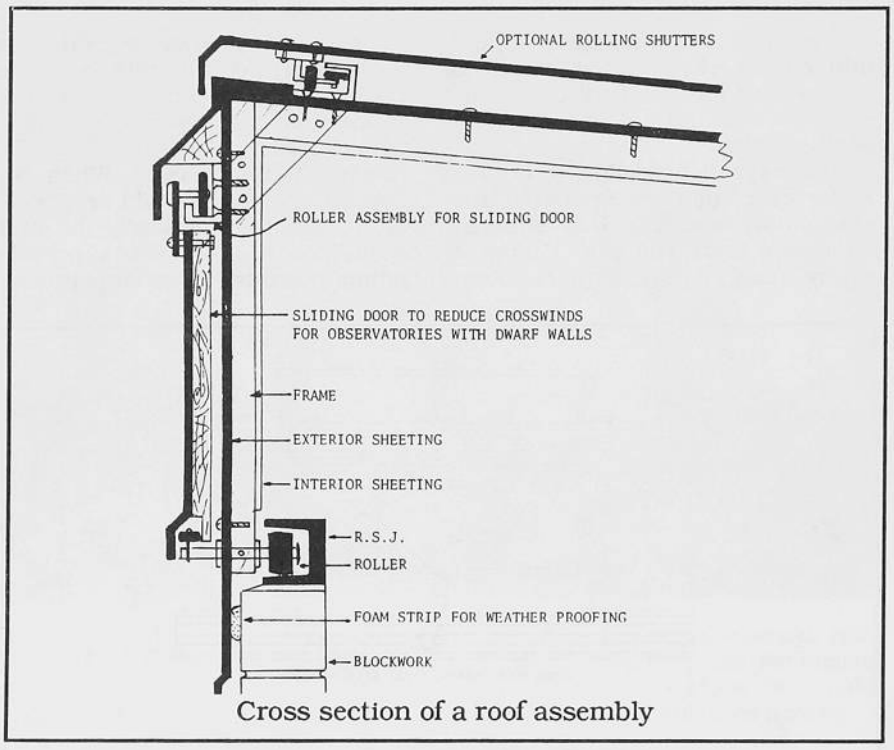
Dome Deficiencies When an amateur decides to build an observatory, a dome is usually the first design considered. Domes provide distinct advantages for large profes-



The versatility of a split roll-off-roof observatory



Sliding roof panels for highly exposed sites



Cross section of a roof assembly

sional telescopes that require high ceilings to accommodate the movements of long tubes. Amateur astronomers, however, have different needs to professional astronomers, not to mention vastly different budgets. Because amateurs seldom have telescopes exceeding 3 meters in length, there is little to justify the cost and building expertise required to construct a smoothly operating, good looking dome, especially when more functional and less expensive designs exist.

Amateur domes often suffer from difficulties in rotating the dome and/or shutter, buckled seams, waterproofing problems, and an amateurish appearance. When the dome is built on the ground, considerable planning, an expensive crane, and crossed fingers may be needed to hoist the finished dome into position.

To build a successful dome, levels and dimensions must be constantly checked when building a dome if it is to operate smoothly. Many domes bind or stick when they are turned.

Finally, domes tend to capture wind from certain directions, sometimes creating fierce whirlwinds around the observer.

Split Roll-Off Roofs After several years of studying and designing observatory designs for amateurs and consequently building an observatory. It has become apparent that the dual-motion, roll-off-roof designs offer many advantages. They provide greater protection than conventional roll-off designs in which the entire roof rolls off to one end of the building. The roof can open above the telescope to create a variable width slit. By moving both sections of the roof, the slit can be moved to the north or south of the zenith. Exposure to wind and cold is thus greatly reduced.

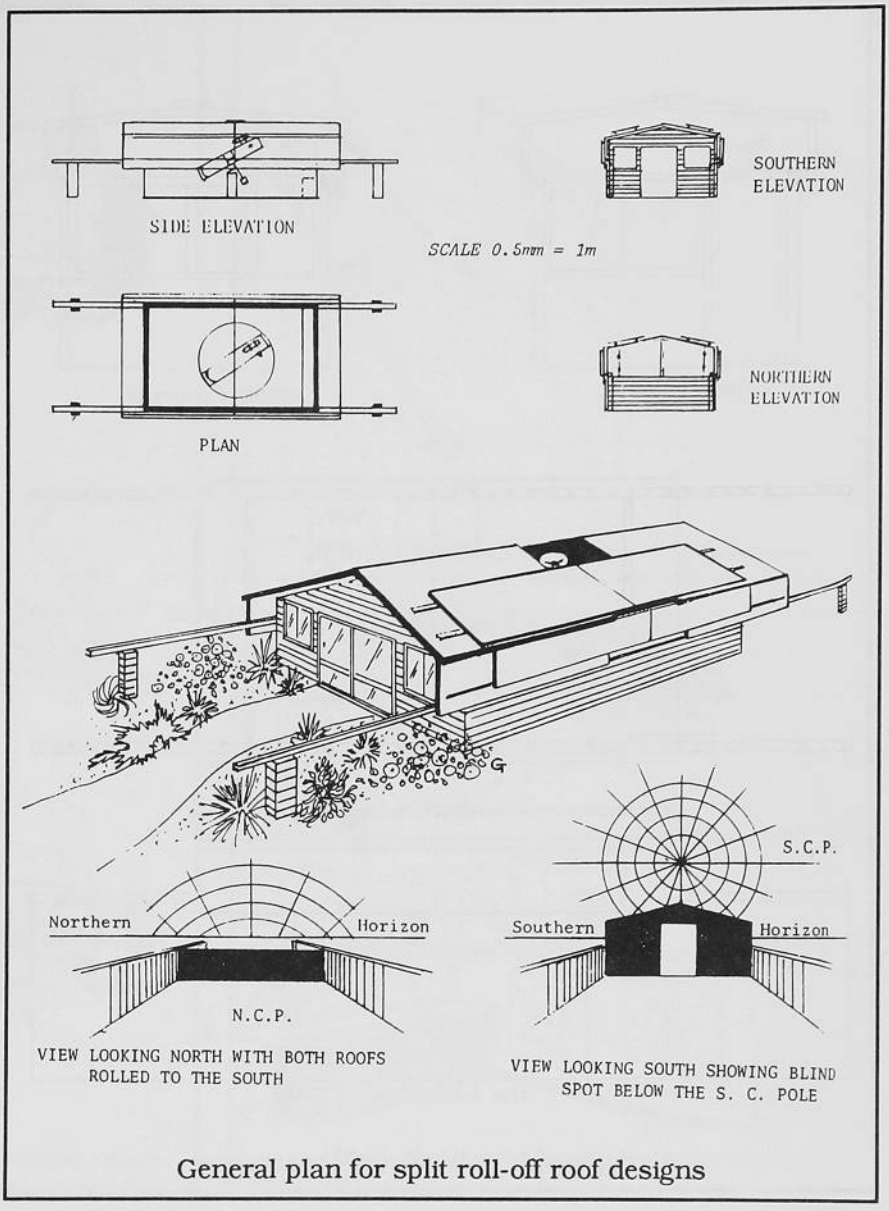
It is important that the observatory be built such that two walls run due north-south to allow the slit to open in an east-west direction. This allows the observer to track an object for a long time without moving the slit. Conventional domes must be moved often when the telescope is pointed toward the north or south.

Varying the width of the slit is most advantageous. On cold, windy nights, the slit may be open little more than the aperture of the telescope. On warm evenings, you can roll the roof back entirely exposing large areas of sky. This is most useful to amateurs who often wish to look around the sky when hopping from one object to another. Others may find this useful when taking wide angle photographs.

If the observatory is likely to be used for public star nights, it is convenient to open the slit wide enough to point out whole constellations to groups of visitors standing in different parts of the observing floor.

The roll-off-roof design can also accommodate more than one instrument if need be. Although the slit has to be opened wider if other instruments are observing different objects, the building still offers considerable protection for the observers. I have on many occasions found this a welcome feature when other astronomers have visited my observatory with their telescopes. It is virtually impossible to use a second telescope in a domed observatory.

The Roof The construction of the



General plan for split roll-off roof designs

conventional roof and walls of a simple split-roof observatory is far easier than that of more complicated domes. This makes it easier for the amateur who has little experience in building to construct a tidy and properly functioning structure.

Tolerances are loose with split-roof designs, allowing errors in construction by an inexperienced builder to cause few problems. Proper operation of a split-roof requires only that the tracks be parallel and level.

The pitch of the roof should be kept as low as practical so as not to intrude unnecessarily on the sky. It is advisable to allow a one-meter overhang at the north and south ends of the roof because this permits the roof to be moved up to one meter off-center before the roof rolls past the end walls of the observatory. This much extra is more than adequate for the majority of observations. It is well worth insulating the roof if you plan to use it as a study during the day.

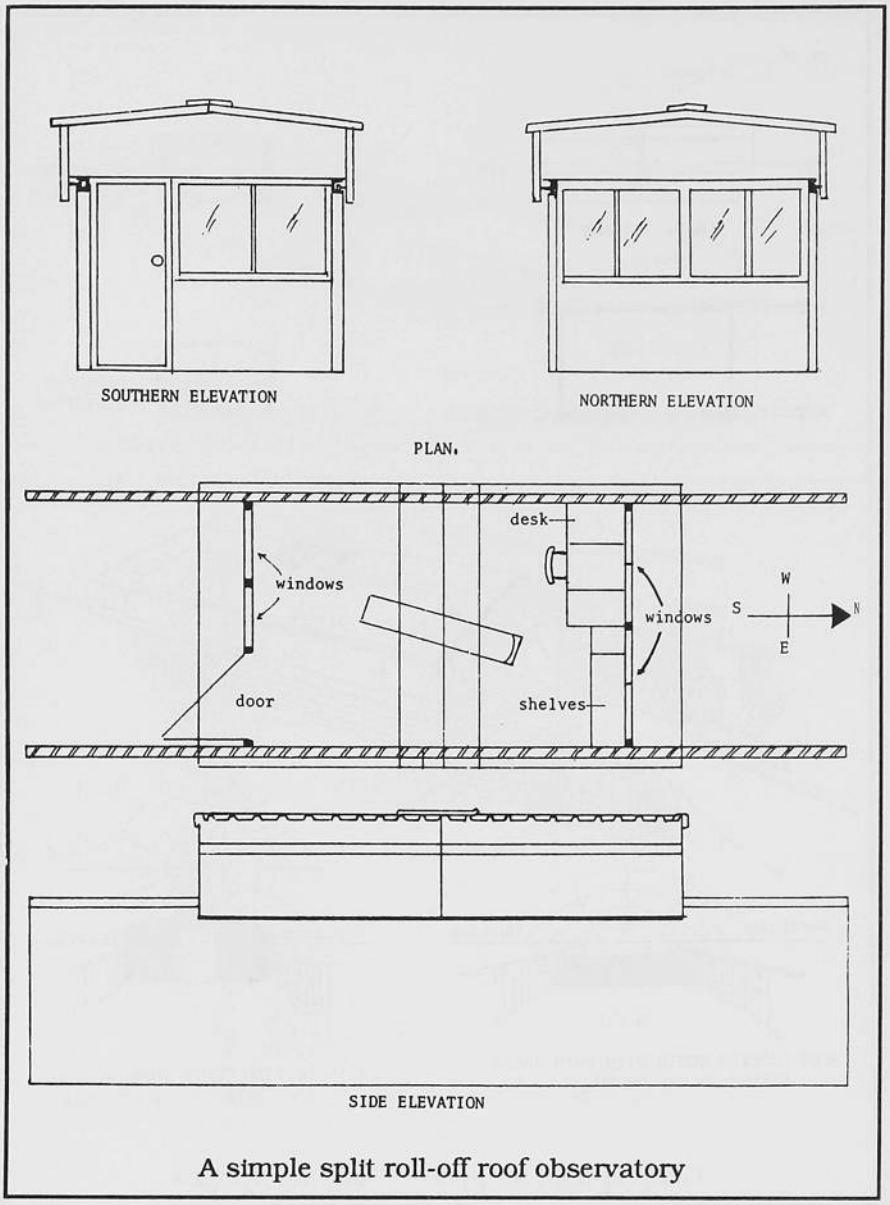
Wind-Proofing An observer with a split roll-off roof suffers less from wind swirling inside than observers in most domes do, and the split roof is capable of more adjustment than the dome slit is. If wind, light, dew or cold threaten to be troublesome at your site, add sliding shields to the roof. These shields can be lightweight with rigid frames that slide out to cover the slit along its opening except in the direction the telescope is pointed. These sheilds offer maximum protection.

Tracks Tracks for the roof to roll on are best made out of U-shaped RSJs. This creates a suitable track in which the rollers may move, and the top of this track protects the roof from lifting during a wind storm. RSJs that are tapered to the edges inhibit rain water from collecting in the tracks.

Tracks must be long enough to permit both roofs to be rolled far enough to permit the telescope to view all the sky visible from the site. If the site permits observing below 15° altitude, then it should be possible to roll both roofs to one end. Doors can be installed in the northern and southern ends of the roof if near perfect horizons are available.

Rollers Roof rollers may be any type as long as they can support the weight of the roof. It is worth purchasing wheels with roller bearings and rubber tires as these roll well and are less likely to wake other members of the family or neighbors who may be sleeping when the roof is moved. If the rollers are placed at one-third the length of each roof from the ends, this will permit the roof to roll well beyond the end of the track, allwoing either a shorter track or increased sky area.

Sliding Doors For sites where wind is a considerable problem, I recommend attaching sliding doors to the east and west walls of the roof. Doors reduce crosswinds that can vibrate the telescope. Lightweight doors made with a pine or aluminium frame covered with light galvanized iron are best. They need only be supported by a simple track at the top and prevented from flapping by a guide at the bottom. The doors need be opened only to view the low eastern or western sky. If your site does not allow you to see any lower than 15° to 20° above the eastern or western horizon, then doors are superfluous.



A simple split roll-off roof observatory

Exterior Walls Because seeing can be affected by differences in temperature between the observatory and the surrounding unding air temperature, it is advisable to make the exterior walls out of a material that does not retain heat. Alternatively, cover the building with material that reflects most of the Sun's heat. Aluminium sheeting and timber cool rapidly as darkness falls, but brick does not.

Painting exterior white will reduce the heat absorbed through the day, but an all-white building may be out of character with its surroundings. A large overhang on each roof or plantings of leafy shrubs can shade exterior walls from the Sun's heat. The east and west walls support the roof and therefore need to be of sturdy construction.

Many amateur observatories with domes have low supporting walls and consequently have dwarf-height doors. The split-roof design eliminates the need for a dwarf door by placing a normal sized door in the southern wall of Southern Hemisphere observatories (or the northern wall of a Northern Hemisphere observatory). This may cause the loss of a small area of sky directly below the south celestial pole, but objects rotate out of this blind spot.

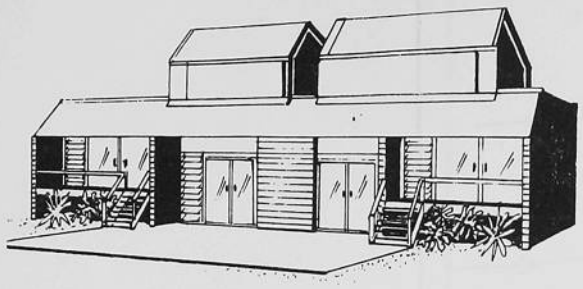
In suburban sites, skies do not permit views much below 15° to 20° above the horizon, in which case the walls may be 2 to 2.5 meters high, permitting normal doors and windows to be built into any wall.

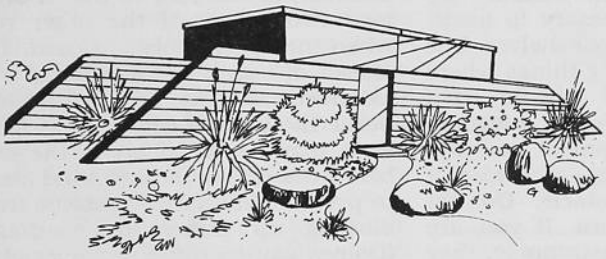
Track Supports Supports for the ends of the tracks need only be simple pillars, but these can appear somewhat untidy in typical structures. Consider using these supports to create pleasing and practical enclosures between the tracks. You have an opportunity to add a car-port, darkroom, or workshop to your observatory. This area may also be used as a greenhouse or garden shed—an incentive for the wife or frowning parent to help justify your building costs. The serious amateur who can afford a country observatory may wish to incorporate a small living area.

The Floor The observatory floor may be either concrete or timber, but care should be taken to mount the telescope independently of the floor. It is well worth the small expense incurred to cover the floor with vinyl tiles, seagrass matting, or cheap carpet. This insulates the observer from a cold floor and helps reduce fatigue during long observing sessions.

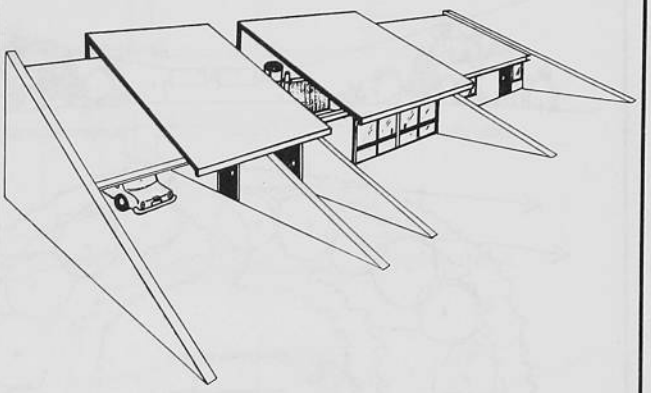
Resale Value With a little foresight you can design your observatory to look attractive and add to the value of your property. If you are building near an existing building try, wherever practical, to use similar materials. In the event of future sale of the property, thought should be given in the design stages to the possibility of being able to sell the observatory as a play-room, cabana, recreation room, or study. A split-roof building could enhance the resale value of your property, being quite a useful, though unusual selling feature. Domes, although expensive, have little or no resale value. You will spend a couple of thousand dollars minimum for a well-equipped observatory; its aesthetic appearance and resale value should not be ignored.

Lighting A very important aspect of any interior is often the most neglected. Observatories are not only used in at night but also in the





Observatories designed for high resale value



Luxury observatory with living quarters

Well-designed observatory interior

daytime, when repairs or improvements are carried out on the telescope and ancillary equipment. This requires plenty of light inside the observatory.

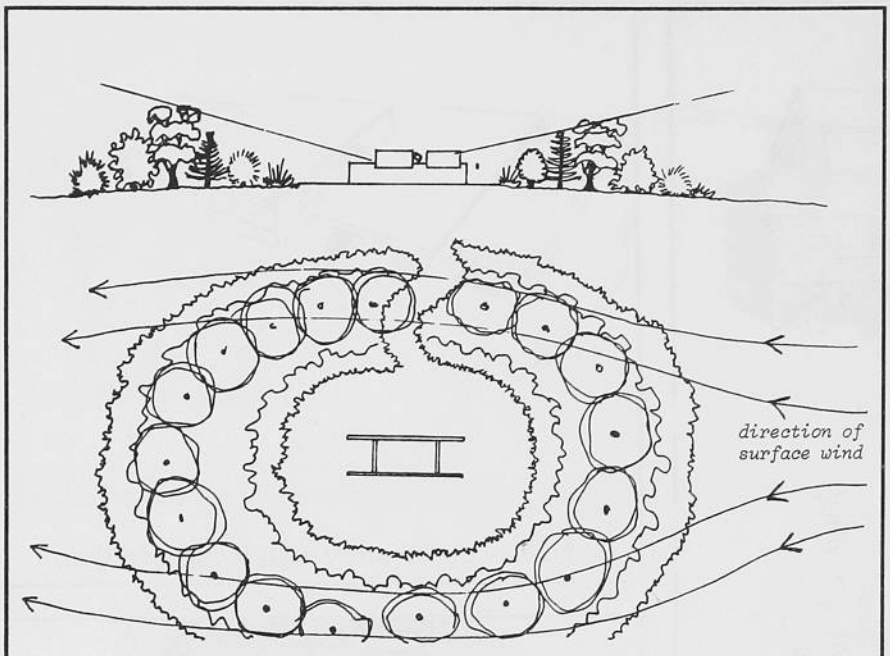
If the observatory is to be used as a study, then windows should be incorporated into the design to provide good natural lighting and ventilation. Domes seldom have windows in their dwarf walls and, if interior lighting is poor, require the shutters to be opened. Windows may require heavy blinds or curtains if it is necessary to block out neighboring lights while one is observing.

Adequate white-light illumination is also needed in the observatory. This is most effectively achieved by installing daylight fluorescent tubes behind pelmets at the top of two facing walls. This diffuses the light by reflection throughout the room and hides the source of the light, thereby reducing the time required for the eye to dark adapt when the light is turned off. The pelmet need only be about 80cm in depth to effectively hide fluorescent tubes if placed near eye level.

An incandescent long-reach, draftsman's desk lamp is a necessity at the work bench. It should have a clip-on red filter or interchangeable red bulb and be wired to a dimmer control. This type of desk lamp Is most useful for controlling the degree and direction of illumination on small items such as star charts, eyepieces, etc., without allowing the light source to shine into the eye.

Because many astronomical programs require the observer to detect faint objects, it is fundamentally important that the observatory be as dark as possible and have faint light only where it is needed — at work centers, desk, observing chair, setting circles, and instrument panels. It is generally far better to have a number of faint lights than one brighter light. I find that a child's night light, correctly shielded around the edges and plugged into an extension cord, makes an excellent hand-held, low-intensity light source. They cost a couple dollars and eliminate the need for torches and batteries.

Some general red lighting is useful if the observatory is likely to have visitors. This allows the movement of people without turning on white lights or having visitors risk injury in the dark. Again, it is best



Creating a wind and light shelter through plantings

to hide the light source and desireable to control the red lights with a dimmer so that no more light the necessary is used.

Electric Power Provision for a double outlet near the telescope mount and at least two double outlets in the vicinity of the desk is wise. The electronics revolution is placing within reach of amateurs much sophisticated equipment such as computers, printers, chart recorders, photometers, intensifier tubes, VDUs, radios, quartz clocks and a multitude of other recording and amplifying equipment. Adequate provision should be made for their present or future installation.

Apart from providing space for racks of electronics, it is worth considering the inclusion of a good cassette deck and speakers if you plan on spending long hours observing. Music and comedy make good company when one is working alone. Soft background classical or modern electronic music can create a sense of awe and excitement when the roof parts to reveal the universe to visitors. If the observatory is likely to be used for public viewing, provision should be made for a slide projector and screen. This can be done by back projection onto a frosted screen.

Storage Be sure to allow for plenty of desk space. Star charts take up a lot of room. Even a large desk is always too small in a well used study. Make the building 0.6 meter longer if necessary to incorporate a desk and bookshelves. The convenience of having things where you want them will pay for itself many times over. Provide adequate storage for all equipment you will keep in the building—otherwise it will become an obstacle. Do not skimp on bookshelves. If you are serious about your astronomy, they will fill rapidly.

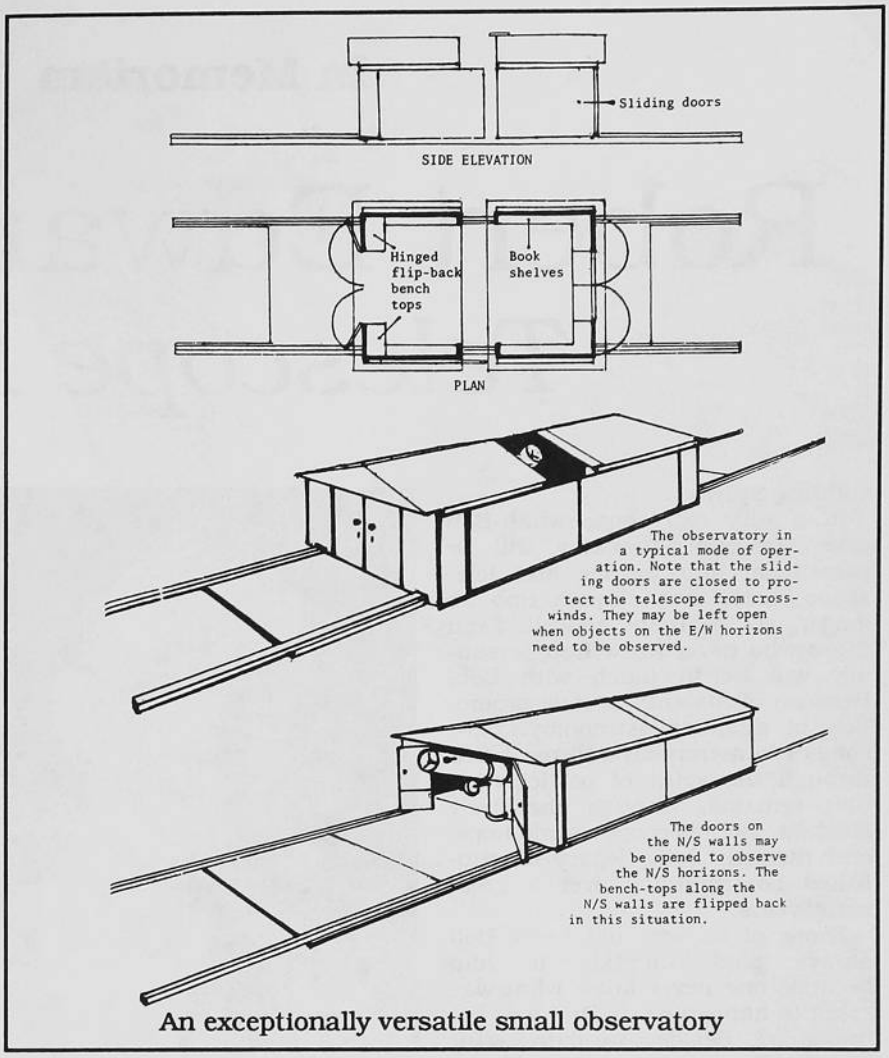
How Big? The observing floor should be as large as your budget will permit, particularly if you are likely to install a larger telescope in the future or anticipate entertaining groups of people in your observatory. It is wise to make the shortest dimension of the floor plan no less than 1 meter wider than the length of the largest telescope it is likely to house. This will accommodate the comfortable movement of an observing chair or people around the telescope.

Interior Design Have the interior of the observatory, walls, ceiling, and floor rather dark. This greatly reduces unwanted reflections. Even the faint light of the night sky is sufficient to desensitize a fully dark-adapted eye. Dark timber, dark matte paint, or dark brick make functional and attractive interiors. I painted the walls and floor of my observatory with matt black paint. White paint "stars" were lightly sprinkled over this and the walls were highlighted with astronomical posters creating a practical, yet appropriate interior. It may be wise to allow for the inclusion of a bed in your floor plan. Visitors also find it a welcome seat while waiting their turn to look through the telescope. Domes seldom have the room for such luxuries.

Waterproofing The join in the roof is simple to waterproof. It requires only that some tinplate be attached to one roof so that it overlaps two ridges of the other roof when the observatory is closed. The sides of each roof should be extended 10 to 15 centimeters below the level of the track. A foam strip may be glued on to the wall below the tracks in high wind areas to prevent drafts and moisture from blowing up under the overhang. (Domes can be quite a challenge to waterproof effectively.)

Landscaping Apart from improving the appearance and value of the site or structure, landscaping can prove most functional. Many fast growing, care-free, inexpensive Australian native shrubs abound on the market today. Several can be used as effective windbreaks exposed regions. If thickly planted, shrubs can also shield your site from annoying neighboring lights. Local nurseries will gladly advise you on the best types of plants to suit your soil and climate. Remember to state the maximum height you can afford your plants to grow.

When you are planting a windbreak in very exposed regions, particularly close to the sea, be sure the shrubs are native to those conditions. If space permits, plant trees around your observatory to form a bowl-like appearance with trees increasing in height with increasing distance from the observatory. The tallest trees should be on the side that receives the strongest wind



An exceptionally versatile small observatory

Thermal Effects It is vital to consider the thermal effects that your surrounding may have on your seeing conditions. Open areas surfaced in concrete, bitumen, brick paving or decorative stone will absorb considerable heat on a hot day and can retain their heat well into the evening. This is detrimental to good seeing.

The solution to this problem is either to shade such heat absorbing surfaces with suitable trees or build the observatory at least 2 meters above the ground. Thermal problems of this kind are not troublesome for deep-sky observing, but are quite noticeable when using high magnification.

Hot air rising out of the observatory slit is a more common problem. A roll-off roof has the option of rolling the roofs wide apart after sunset to quickly dissipate warm air that may have accumulated inside the observatory during the day.

Another significant thermal problem is caused by the heat plume which continually rises from the human body. The simplest way to avoid this is to fit a light weight tube 1 meter long over the open end of the telescope. The warm air then rises around the outside of the tube rather than through the optical path.

Alternative Designs If your budget is very limited, you can still build an observatory for as little as $200 (Australian) using second-hand materials. It is basically a shed type of observatory. The shelter rolls apart along a track on the ground. Sliding doors are attached to both the east and west walls to act as wind protectors. For amateurs who are likely to change their abode and who have little money to spend on rebuilding, I would suggest that the walls and roof be either bolted or hooked together to facilitate easy dismantling and setting up elsewhere. If you cannot afford a concrete slab, then the floor need only be a trailer load of brick paving or old linoleum laid on the ground. A large version of this design would prove to be a practical and cost effective club observatory. It can also accommodate more than one instrument at star parties.

Summary I have shown that split roll-off-roof observatories have the following characteristics:

- they offer the observer more protection from the elements,
- they are more versatile,
- they are easier to construct,
- they cost less than a dome with the same floor space,
- they allow easy tracking of objects across the meridian,
- they have an adjustable-width slit opening,
- they permit whole-sky viewing,
- they are easier to waterproof,
- they are unlikely to catch wind,
- they are easily designed to blend into the environment,
- they can accommodate more than one telescope,
- they offer normal door and ceiling heights,
- they have higher resale value.

In conclusion, the split roll-off-roof design offers major advantages over domed observatories for amateur astronomers.

The new generation of professional observatories no longer use domes to house their instrument. As this trend continues, the amateur's desire to build a miniature Mount Palomar in his or her backyard will wither, and amateur astronomers will consider the practical aspects of observatory design.

I wish to thank my wife Karen and my friend Peter Anderson who offered useful comments on the subject over past years.

Gregg D. Thompson
7 Stover Court
Springwood, Queensland
Australia 4127

In Memoriam

Robert Edward Cox, *Telescope Nut*

Guiding Spirit

In a very real sense what Bob gave amateur astronomy will be present at star parties and telescope meets even though Bob no longer will be there himself. Even those who never knew Bob personally will be in touch with Bob. Because of his enthusiastic promotion of amateur astronomy, newcomers to astronomy will meet Bob through the spirit of participation that remains, through the lively conduct of telescope workshops, and through Bob's legacy of published contributions over a great many years.

Those of us who did know Bob always paid attention to him because one never knew what was going to happen next. That was his trademark. Besides, we didn't want to miss the punch line. I recall one stellar performance at a lecture on optics that Bob gave at a Mid-States Convention some years ago. In the course of the talk, Bob describes the Schmidt corrector, and he tells us that one has even been made by a precocious amateur.

Bob calls the young person to the stage and commends him for an exceptionally fine job of figuring. But as Bob gingerly lifts the plate from its box and holds it up to the light for inspection, it slips from his fingers, crashes to the floor, and smashes to smithereens.

Time stands still; empathy builds up in a long awkward silence as the accident is appraised. Suddenly, with a characteristic chuckle, Bob quips: "Well, that's what you'd expect from window glass."

Window glass? Of course! It was a set-up. Although we were were shocked wide awake and we knew we'd been had, we were much relieved.

More than any other person Bob influenced my interest and participation in amateur astronomy and telescope making. Bob Cox will be present again whenever I think of telescopes.

— A.L. Woods

Good Friend

I considered Bob and Hilda good friends. Hilda sent us a Christmas card and I read between the lines that all was not well. On December 17 I decided to call Bob to wish him a happy holiday, but was stunned when his granddaughter told me her grandad had passed away the day before.

I first met Bob when he came to Riverside in 1970. It was the first year we had awards: a First Place, Second Place, and Third Place for Optics and Mechanics. Bob suggested we have merit awards instead, explaining that places caused competition, whereas with merit awards all awards were equal and we could recognize all sorts of innovative work. Anyway I bought it, and we've been doing it that way ever since.

Bob was a good friend of the amateur astronomer and he will be missed by all who knew him. He was an innovator and shared humorous stories in every conversation about his favorite subject. Bob challenged us, he was forthright, and he spoke his mind to help others in their quest for the stars with optics and telescopes.

— Clifford W. Holmes

Practical Joker

Bob loved practical jokes and loved sharing a joke with friends. On one occasion Bob, with an assist from his identical twin brother Ed, put one over on Don Zonner, the editor of "Popular Astronomy." Bob had Ed approach Don's front door and ring the bell. Don opened the door, greeted "Bob," and invited him in. They were several minutes into a discussion when the bell rang again. Don went to the door to be greeted by a second "Bob Cox."

Bob played another prank at a surprise fiftieth birthday party for Thane Bopp, held on the occasion of Thane's forty-ninth birthday. Bob's gift to Thane was an aberration-free eyepiece with 100% light transmission. You can imagine Thane's enthusiasm and then his expression as he looked through an empty eyepiece barrel.

Bob especially loved to put a practical joke over on an audience. At one convention where Bob was speaking before a large group, a boy Bob planted in the audience brought a Schmidt corrector plate for Bob to inspect. The boy explained that he had spent many hours making it and seemed to be proud of his effort. Bob took the plate from the boy and carefully inspected it from all angles while making comments about what he was seeing to the general audience. He told the boy and the group that the plate had been well done. While

doing this, the glass slipped from his hands and shattered as it hit the floor. Although he explained that it was a joke, the performance was so convincing that some people were mad at Bob for years.

Kidding aside, Bob was once almost injured by a meteor. While he was looking through a 12.5-inch reflector at a star party, a very bright meteor suddenly sped across the field of view. Bob said he was so startled he nearly fell off his ladder.

Bob's great love of astronomy spanned his lifetime. It was an interest, a passion, and even a source of comfort. While stationed in the Christmas Islands during WW II, many of the soldiers were lonely and homesick in the unfamiliar environment. Bob, however, would look up at the night sky and feel at home. A galaxy of familiar friends brought comfort to an American GI.

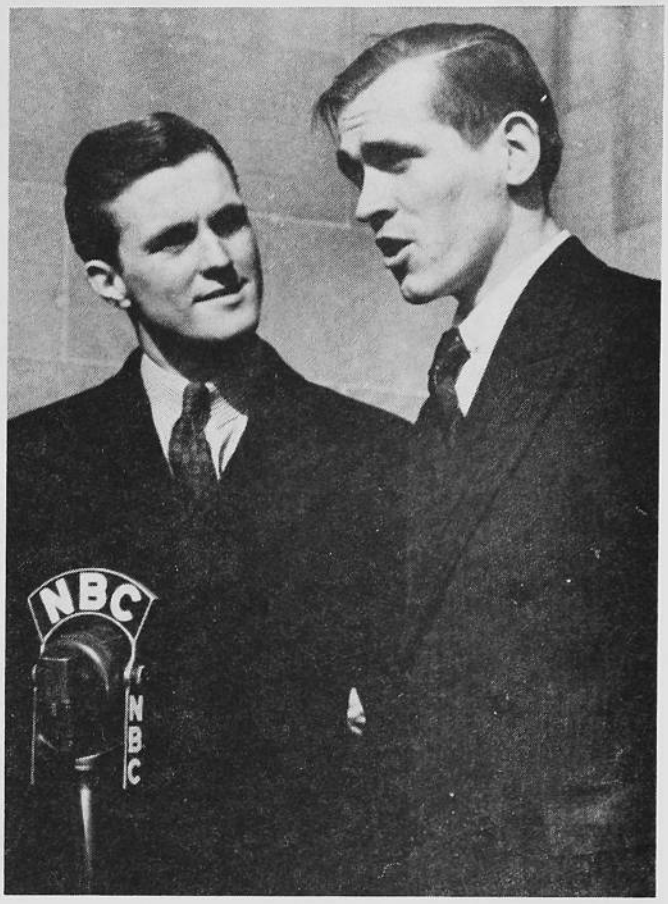
—Wayne Clark

Helping the Beginner

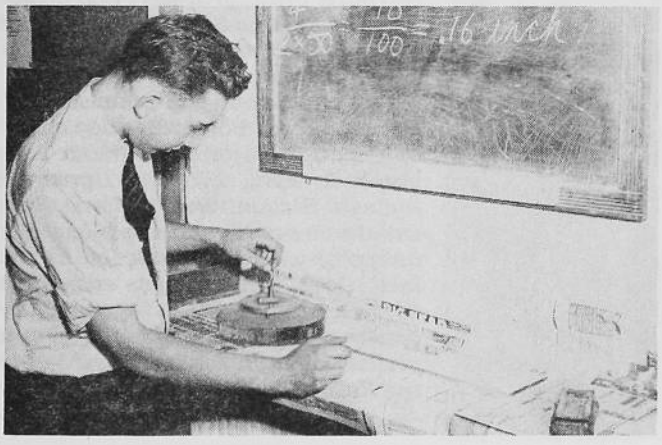
Bob was unfailingly helpful to the beginner. I first met Bob at the 1966 Astronomical League Convention in Milwaukee. I had already built several successful telescopes and had become intrigued by the concept of a dual-field telescope based on the afocal or Mersenne configuration for a two-mirror telescope.

This telescope uses a paraboloidal primary and a smaller paraboloidal secondary, either convex inside focus or concave outside focus, to recalculate the light brought to the focus by the primary. Another smaller optical system then refocuses the collimated beam of light. We would thus have a small telescope lurking inside a big one.

The sexy aspect of this design is



New York: *Bob takes his turn polishing the 20.5-inch mirror of the Optical Division of the AAA. Clockwise: Bob photographed this telescope making class at the Hayden Planetarium. In April 1940 Bob supplied the telescope for the first televised astronomical event—a partial eclipse of the Sun. Here he stands beside an NBC announcer. Lou Lojas and Ed Hanna bevel the edge of a mirror, and Paul Luce using a spherometer during AAA classes, in photographs Bob made. Previous page: Bob and his second telescope, a 10-inch f/7.2 reflector, taken in 1937.*



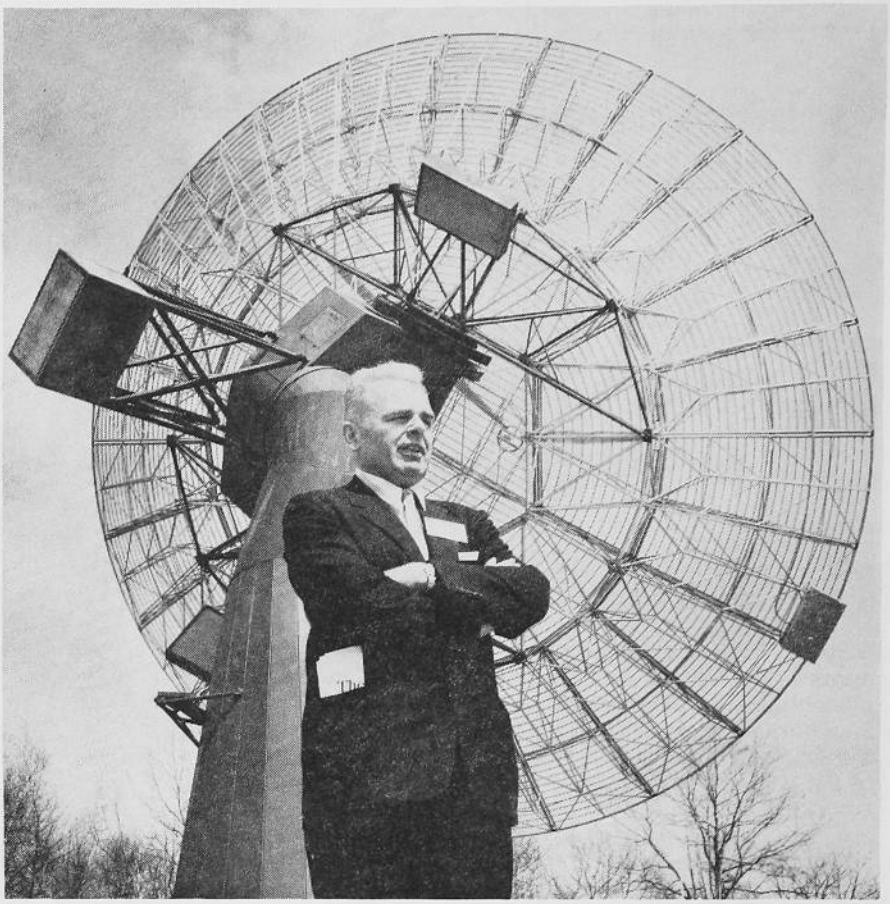
that if the refocusing telescope is allowed to have a wider field than that subtended by the telescope's secondary, the view becomes a low-power ring surrounding the high-power view through the complete optical system.

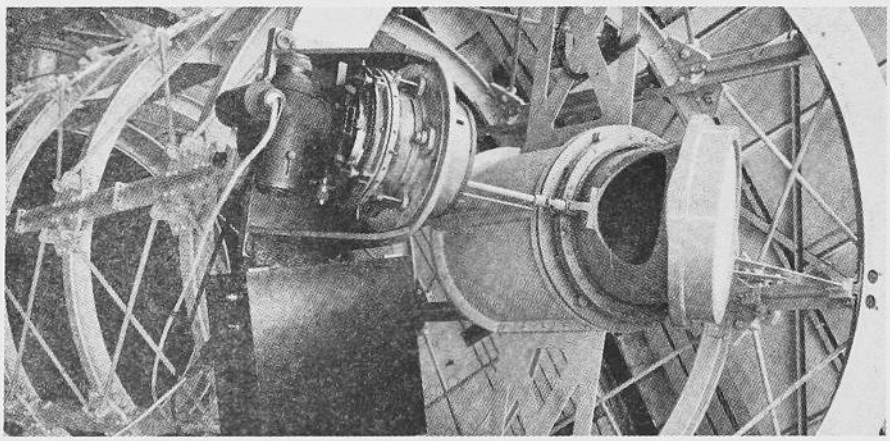
Bob had printed an article on the dual-field application of the Mersenne design in his *Gleanings* column and I thanked him for printing the design and added my (modest) opinion that this concept would certainly be a breakthrough in amateur telescope construction.

Ah, the optimism of youth! This design has several serious flaws: (1) it's made of more optical elements than more common designs; (2) the alignment of the elements is at least as critical as with other compound designs; and (3) its high-power field is extremely limited.

On a more limited scale, my enthusiasm for this design was the ATM's equivalent of the inventor who told his friend that "I've just invented an antigravity machine and I only had to break one law of physics to do it." Bob could have put me down by pointing out that what was obvious to him (and certainly to many others) and should also have been obvious to me. I've since seen many so-called experts in the ATM field treat neophytes in just that manner.

For what Bob actually did I will always be grateful. In the middle of a very busy day in a very busy hotel meeting area, he sat down and explained to me some of the fundamentals of analyzing optical designs for practicality. He also gently pointed out that not every design he printed in his column is one the average amateur should build. Rather, printing the details of a par-





Harvard Photographer: *Bob photographed Harlow Shapley at his desk in 1942. According to Bob, this was one of Shapley's wife's favorite photos of her husband. Clockwise: Bart Bok posed for Bob at the dedication of the 60-foot Hardvard Radio Telescope, in April, 1956, at Harvard's Agassiz Station. Henry Norris Russell discusses the latest advances in astrophysics with students in the late 1940s. The business end of the 61-inch reflector at the Agassiz Station in the fall of 1948, showing a photoelectric photometer mounted at the Newtonian focus.*

ticular design may be done to stimulate the readers' thought. At a time when Bob could have been renewing old friendships or basking in the glow of his admirers, he made a new friend and increased the admiration I already had for him.

If I ever achieve the notoriety in amateur astronomy that Bob Cox did, I hope I will be half as graceful in dealing with beginners as he was with me. Adieu, Bob. We'll miss you. May you receive the rewards in the next continuum you've earned in this one...

—Rick Shaffer

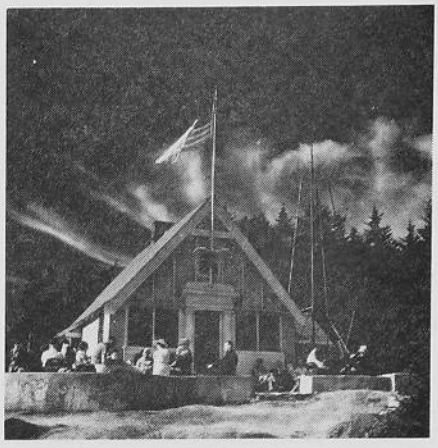
Class Act

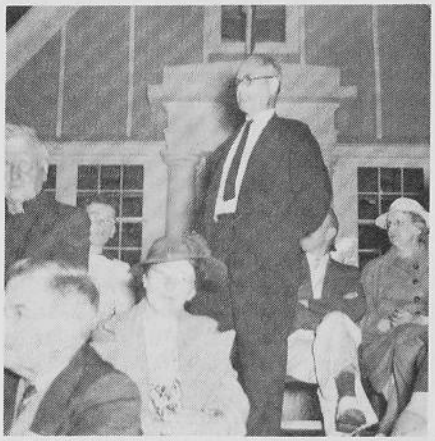
After hearing of Bob's death, I stopped to think of his many contributions to the hobby of astronomy.

I first talked to Bob in 1969 while I was working at Coulter Optical. At the time, I knew very little about the hobby and even less about optics. Bob had called to speak to Jim Jacobson, the owner, but Jim was out at the time. Bob proceeded to spend the next half-hour talking about the hobby and some new optical systems that he was involved with. What struck me so strongly was Bob's unbridled enthusiasm for the hobby. Here was one of the more prominent men in the field spending a half hour of his time speaking to a seventeen year old kid.

That first conversation led to many more. All encounters with Bob were much the same, with me starting with a specific optical question, Bob answering it, and then going on to tell me of some new telescope or eyepiece system that he wanted people to know about.

I think I can safely say that Bob contributed more to the hobby than anyone I know of. His willingness to





Early days at Stellafane: *Russell Porter, deeply involved in the Hale Telescope project, discusses observatories with Jim Grant and George Placky of the New York AAA. Clockwise: Albert Ingalls' favorite photograph of "the little pink house," taken early one morning in the late 1930s. Ingalls speaking at Stellafane in an evening session. An associate editor at Scientific American, Ingalls was instrumental in popularizing telescope making in America. Henry Paul, center, posed for Bob's camera with his 90° wide-angle camera at Stellafane in 1948.*

share his wealth of knowledge and his enthusiasm for the hobby made him, in my mind, a "class act."

— Steve Murdock

Technical Innovator

"Okay, where is it?" someone asked, as soon as Bob Cox walked in the *Sky & Telescope* offices in Massachusetts during a 1972 visit. Bob proudly whipped out his HP-35 pocket calculator, the first one any of us had seen. I was a newcomer on the staff, and editor Joseph Ashbrook still used a Friden mechanical calculator. (Its gears whirred into action several times a day whenever Joe needed a square root or something.)

That was typical of the Bob Cox I came to know. He quickly latched hold of any worthy innovation — as he did more recently when he was among the first to champion the Pretoria eyepiece. From 1956 to 1977, the years he conducted our magazine's *Gleanings* department, he kept his eyes peeled for new optical designs, bench tests, and clock-drive ideas. When presenting these to readers he often added an Editor's Note to help forestall workshop difficulties that might be encountered. To all ATMs of my generation he became the clear successor to Albert G. Ingalls and Russell W. Porter, who had founded the telescope making hobby in America earlier this century.

Indeed, Bob brought to the hobby something neither Ingalls nor Porter could. His years in professional optical fabrication uniquely qualified him. He saw himself in a protective role, standing between unbridled optical designers on the one hand and enthusiastic but gullible readers on the other. These amateurs might try anything, only

to falter if tolerances or proper collimation proved out of reach.

While growing up in Brooklyn, New York, Bob had made his first 6-inch reflector at age 16 back in 1933. Within four years he helped to found the Optical Division of the New York Amateur Astronomers Association, which helped its mirror-making classes in the basement of the Hayden Planetarium. There he began a lifelong close friendship with Charles A. Federer, Jr., another Hayden staff member, who moved to Massachusetts in 1941 to launch *Sky & Telescope* magazine.

After wartime service as a weather specialist in the South Pacific, Bob returned to Massachusetts and began working nights for the magazine. By day he was a photographic technician at Harvard College Observatory, then later an optician at Boston University's Optical Research Laboratories (forerunner of Itek) and the A. D. Jones Optical Works. In 1960 Bob moved to Missouri to join McDonnell Aircraft Company (later McDonnell-Douglas), to supervise the optical shop making prototypes for fighter planes and manned spacecraft.

From the amateur's point of view, the late 1950s and 60s brought many exciting optical developments not covered by Ingalls' ATM books. Through Gleanings Bob helped introduce the Schiefspiegler of the German designer Anton Kutter. England's Horace Dall extended the Dall-Kirkham design to include a transfer (relay) lens. America's John Gregory came up with his famous variant of the Maksutov Telescope. Richard Buchroeder, a rising star at the University of Arizona's Optical Sciences Center, began exploring tilted-component telescopes in a more general way than Kutter had.

All these innovators got Bob's enthusiastic backing, for they used mainly spherical optics. He often reminded readers that a spherical surface was the easiest to make and simplest to test and the most foolproof for amateurs to undertake.

Yet, sometimes what an editor rejects comes back to haunt him. Bob was initially skeptical of the John Dobson's approach to large reflectors, partly because he worried about the image quality from thin blanks of porthole glass. In the 60s and 70s he also avoided publicizing Arthur Leonard's Yolo designs (recently revived and extended by Jose Sasian). The original Yolo depended on a mechanical warping harness to give one of the two mirrors a "potato chip" twist. Today the warping harness is a cornerstone of the Keck 10-meter project, and a large part of the astronomical community is still quite leery of the idea. (Time will tell.)

Whenever Bob showed up at Stellafane, Riverside, and countless other gatherings of amateur astronomers his natural exuberance came out. He always seemed to be bubbling over with enthusiasm and new ideas to try. Above all he taught us that telescope making can be a whole lot of fun.

— Roger Sinnott

Always There

I was deeply saddened to learn of the passing of Robert E. Cox. I cannot think of another person who has spent more time and energy promoting innovations in optics and amateur telescope making. In his undying quest for the perfect (Bob would have said "near perfect") all-spherical telescope, he encouraged the development of many of the designs that we will be talking about, reading about and building for years to come.

My first contact with him came about in 1965. At that time, I was

PHOTO BY ROBERT E. COX: *David Woodbury and Albert Ingalls discuss the Hale telescope over breakfast. Woodbury wrote "The Glass Giant of Palomar," a classic in the popular literature of astronomy. Below, left: Members of a late-1930s telescope class at the Hayden Planetarium, representing both the young and the old, fine grind 6-inch mirrors. Telescope making helped put astronomy in the public eye. Paul Luce polishes an 8-inch mirror in the AAA workshop. Below: Porter explains an unusual mounting considered for the 200-inch telescope.*

14 years old and lived between Pecos and Verhalen, Texas. There, where I was able to enjoy a TSP every night, I got the unquenchable desire to build a 6-inch Newtonian. Unfortunately, the local libraries were very limited in their selection of material relating to telescopes. Finding Bob's name and address at the end of an article in *S&T*, I decided that he might be able to advise me on locating publications on mirror making. Buying a reasonably good telescope was out of the question. My parents had pinched pennies for three months to come up with $16.00 for a 3-inch Gilbert with a paper tube.

I had never written to an "Authority" on anything before. I can remember my mother assuring me that Bob was a busy man and that I should not expect a reply. However, in less than two weeks I received a thorough reply (with diagrams relating to mirror grinding), a copy of *S&T*, and an address where I could obtain a copy of A.J. Thompson's "Making your Own Telescope."

Bob and I corresponded regularly over the years and at an accelerated rate after he got his personal computer and started tinkering with ray-trace programs. Although I have been a professional optical technician and ATM for many years, I do not posses the mathematical savvy to understand many of the engineering principles that one with such an interest and dedication should have. While some of the more experienced telescope makers I knew would get exasperated with my endless stream of elementary questions, Bob handled each one as if it was of profound importance. Thus, I was allowed to keep my self esteem while learning at my own slow-as-a-snail pace.

Bob was always there—for all of us. I hope someday to see an annual award for excellence in amateur telescope making, created in his honor and bearing his name.

—William Cook

Tough and Determined

In 1978, when Charlie Federer told Bob that *S&T* no longer needed him to do *Gleanings*, Bob was shocked. I suspect that he called me the same day he received the letter and offered to write articles on telescope optics for ASTRONOMY. We quickly agreed on the topics he would cover, and Bob set to work churning out stories.

That summer Bob and I met at one of the amateur conventions to talk over his stories. I recall sitting opposite Bob in some dining hall or cafeteria long after our food was eaten as Bob outlined his concern that amateur telescope makers needed support, support he felt *Gleanings* would no longer provide, and that ASTRONOMY, a non-technical magazine, could not provide. He wanted us to start something like the Maksutov Club Circulars. He even had the title figured out: "TeleOptics."

I went back to Milwaukee and mulled over what would be involved in doing a newsletter with a circulation of perhaps 2,500, my estimate of the number of serious ATMs in the United States. There was no doubt in my mind that amateur astronomy needed such a publication for its long-term health.

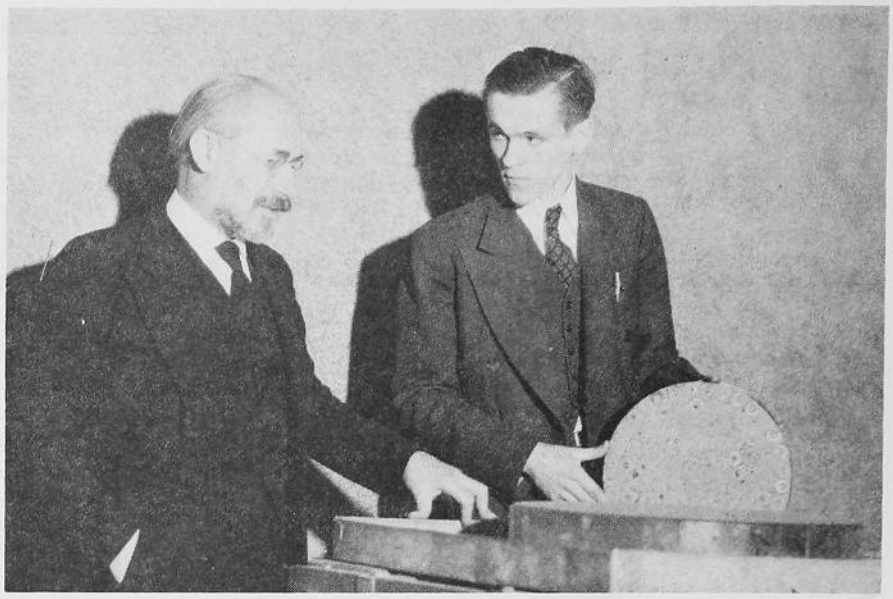
I soon proposed to Bob that we name our new publication *Telescope Making* to broaden its appeal beyond optics. A bit to my surprise, Bob thought it was a good idea. Although he did not like the trend, he could see that amateurs were buying mirrors instead of making them, and that only a hardy few were making Maksutovs and TCTs.

I based the proposed name on three years experience teaching mirror-making at the McLaughlin Planetarium. I had seen that most of the mirrors we made never became part of a working telescope. Bob and I both wanted people to make telescopes, not just mirrors. We would split the work: I could run the mechanical side of *Telescope Making* while Bob handled the optics.

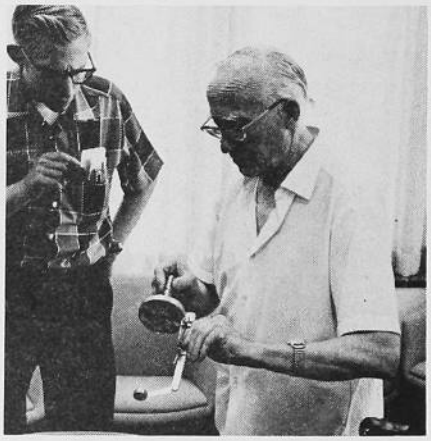
In the ten years I worked with him, Bob never failed to amaze with his energy. During the years he was healthy, I had letters and phone calls from him all the time. Calculator programs (which I was never fond of) arrived by the score. When Bob graduated to an Atari 800 and later a PC clone, the flow of programs continued. Meanwhile, articles from Bob's friends poured in. Bob gathered stories about lens-making, Schiefspieglers, optical supplies, and relay telescopes.

The year we covered RTMC together Bob practically ran me off my feet. He buzzed back and forth from telescope to telescope, now listening and learning, now teaching and telling. He'd hand me a handful of scribbled notes on telescopes he'd found hidden down by the lake or at the extreme end of Telescope Alley, then run off to give a talk, conduct a workshop, shoot pictures of telescopes, laugh about old times with his cronies, or chew the fat with a circle of admirers. That year his jacket, tie, and white shirt won him the Edward R. Byers Non-Memorial Award for Outrageous Overdressing at the Conference that year, making Bob the honored recipient of the first Bozo Award, and his years of service to telescope makers everywhere won him the Clifford W. Holmes Award.

Beneath the joking exterior was a man as tough and practical as they come. Bob loved astronomy and telescope making, and was determined to spread the word to everyone who would listen, and nothing was going



A Love for Optics: *Ed Hanna coring the New York AAA's 20.5-inch mirror. Bob shows George van Biesbroeck how the club is grinding its large mirror. At Perkin-Elmer, Bob photographed Ted Mogey figuring a zone in a corrector plate for a large Schmidt camera. Dick Buchroeder and Horace Dall examine Dall's open-tube relay telescope.*



to stop him. He honed his talks to perfection, adding the right mix of salty humor, kidding around, and terrible puns to keep the audience groaning, but nonetheless on the edge of their seats and listening to every word he had to say.

At the core of everything Bob did was a burning desire to put good optics into the hands of the amateur. He invested several years trying to interest commercial telescope makers in selling a 3-inch Schiefspiegler similar to the one Oscar Knab described in *TM#1*. Although that product never materialized (it was too hard to align them on a production basis), Bob continued to watch the optical industry like a hawk. His early enthusiasm for Schmidt-Cassegrains faded during the Halley era, although he had championed this design in its early days. He also campaigned quietly for better quality Dobsonian optics.

Personal computers finally convinced Bob to relax his long-held stance on delaying publication of new designs (i.e., "paper telescopes") until they had been prototyped. When he could ray-trace new designs himself, Bob carefully checked tolerances and performance for every design we published in *Telescope Making*.

Bob Cox's drive served the amateur astronomer and amateur telescope maker well for many years. Bob brought the working optician's practical viewpoint to the amateurs thinking of building a telescope. And Bob was determined and tough enough to campaign for quality optics for amateur astronomy, so that youngsters and newcomers would find the stars as wonderful as he himself found them.

— Richard Berry

Bob Cox in the Eighties: *Bob's interest in astronomy never seemed to fail him. At the ALCON meeting in Waukesha, Wisconsin, Bob and Scotty Houston engage in spirited discussion. Bob and Hilda Cox at home during the early 80s. At the time Bob was retired, had acquired a computer, and was getting started in optical ray tracing. Bob and his "twitcher" telescope. Bob loved to "twitch" amateur astronomers by pulling this small package from an inside jacket pocket and unfolding it into a complete astronomical telescope.*

Special Friend

On December 16 1989, with the passing of Bob Cox, my family and I lost a unique and special friend. Bob was not only an "astronomy friend" but also a family friend. When he visited with my family, he was like another grandfather to my kids. The pleasure he obtained from roughhousing with them was just one manifestation of his vibrant, enthusiastic personality.

I first met Bob in 1960 when he came to work at McDonnell Aircraft in St. Louis (Hilda came from this area) where I am employed, so I had the pleasure of knowing him for almost thirty years. In those years I got to know a man who was both a perfectionist when it came to optics, and a strong enthusiast when it came to new ideas in optics.

Bob was self-taught in the math of optics; he never attended college. When computers and programs for optics became available, Bob became a computer enthusiast. Toward the end when he could no longer push glass, he "let his fingers do the pushing" on his computer.

During World War II, he was stationed on Christmas Island in the Pacific and served as a weatherman. Although the military would not tell him where his unit had been assigned, Bob's knowledge of astronomy allowed him to find out. Using his watch and sighting on Polaris, Bob did his own navigation to keep track of the ship's path, so knew where they were going.

In conclusion, I could not say it better than my daughter Elisa (then eleven years old) said when she saw how sick Bob was the last time she saw him. She said, "but he is such a nice man!"

—Thane Bopp

The 1990 Winter Star Party

Twenty-six hours behind schedule my plane lifted out of Milwaukee. The snow-covered landscape below—still-white roads, drifted-in yards, snow-covered roofs—testified to the strength of the storm that had closed down Mitchell Field the day before. I was tired of waiting—waiting for the plane to be de-iced that morning, of waiting the night in the Ho-Jo's near the airport, of reading and writing away the day, while outside the terminal the snow accumulated at a steady two inches per hour. When I finally pulled down the drive at Camp Sawyer, it seemed like a miracle to have arrived, because my sleeping bag had *not* arrived. That night I pitched my tent, snuggled down into a pile of blankets I had borrowed from Ron Ravneberg (thanks!), and passed out.

The Winter Star Party this year was the first big astronomy meeting of the 1990s. Some 362 persons attended, completely filling the site. Problems with broken plumbing, full portapotties, the monsoon rains, and cloudy skies hardly dented the enthusiasm of those who attended.

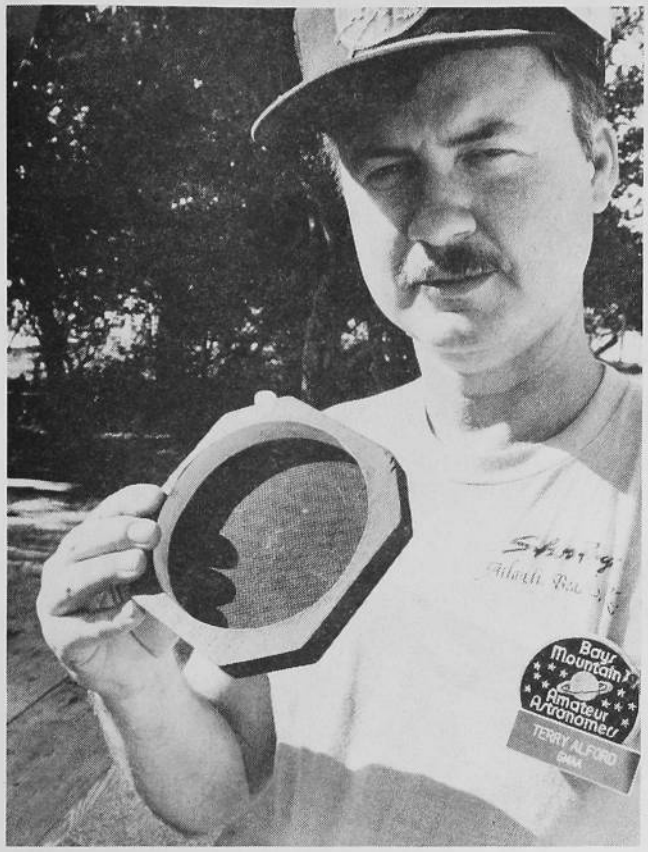
On Saturday morning I woke to sunlight streaming through the canvas of my tent. Birds were singing. The sticky sensation of humidity, wearing a tee-shirt outdoors, sunlight on my skin, and the good smell of green plants seemed a far cry from Milwaukee. I drove to Island Jim's Restaurant for breakfast and a clean washroom. And their walnut-raisin waffles are out of this world.

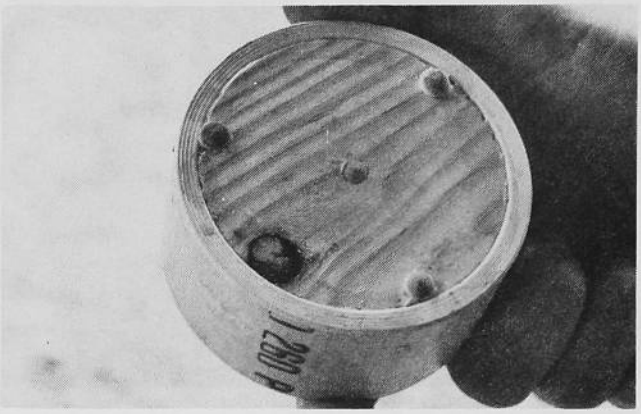
As the pictures in this brief story show, there were plenty of interesting telescopes at the WSP. For my money, Andy Johnson's d'Autume equatorial platform stole the show. Make no mistake: Andy builds it as a product to sell. But the ideas embodied in it are superb. I hope the d'Autume platform heralds a decade of innovation.

The meeting's best "hot tip" came from John Murphy. Devices called camlocks, he says, are perfect for telescope makers who need to join tube sections. Camlocks are glorified suitcase clasps, and are precise and adjustable. Piedmont Equipment Company (401 W. 32nd, Charlotte, NC 28233, 800-438-4120) sells big ones (the latch is PN 32000-7508; the keep is PN 32000-7518). Camloc (601 Rt. 46 W., Hasbrook Heights, NJ 07604) has all kinds of adjustable stainless steel fasteners. Call 201-288-8300 for the name of a local distributor. Part number 51L1-1-1BF includes a latch and keeper.

Saturday evening was clear and that night no telescope sat idle. Jupiter was glorious—good enough to be worth the trip.

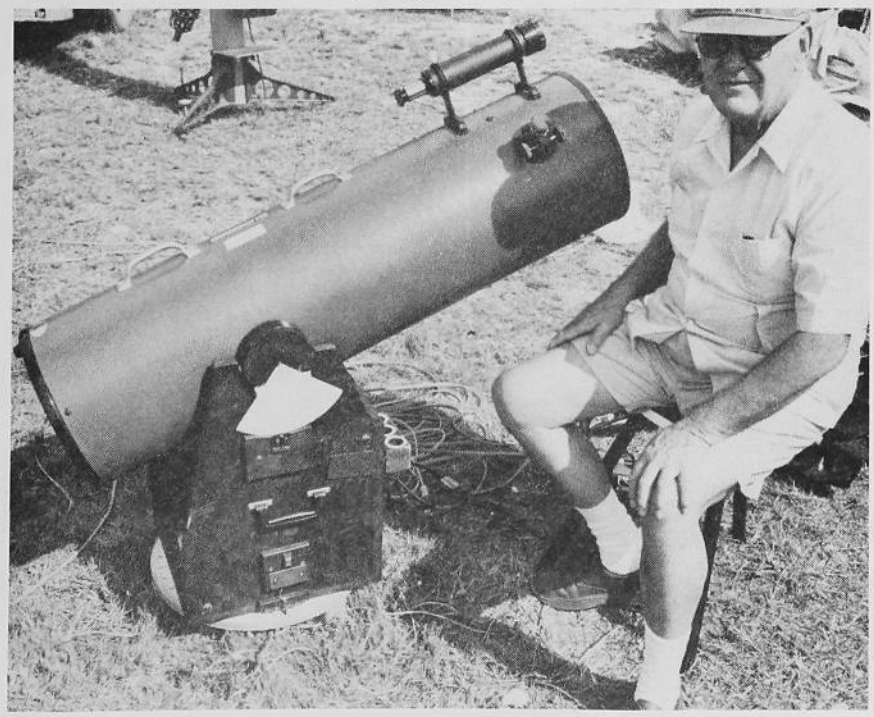
—RLB

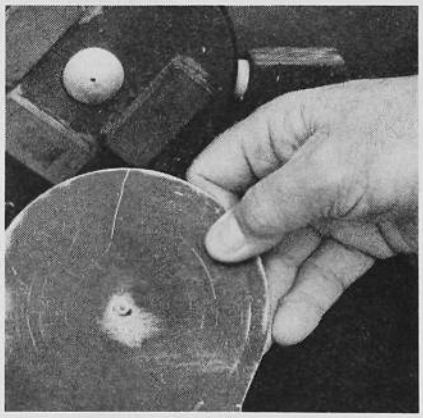


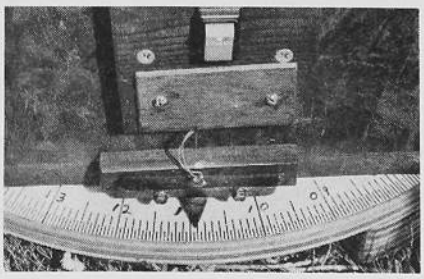


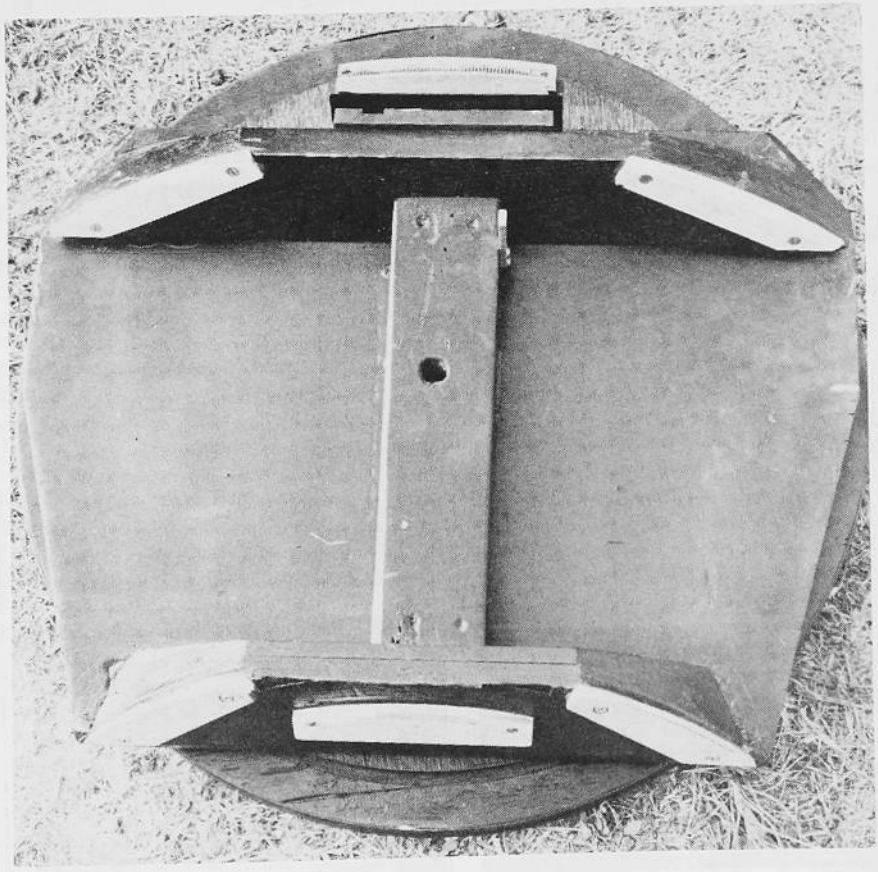
Why Didn't I Think of That...

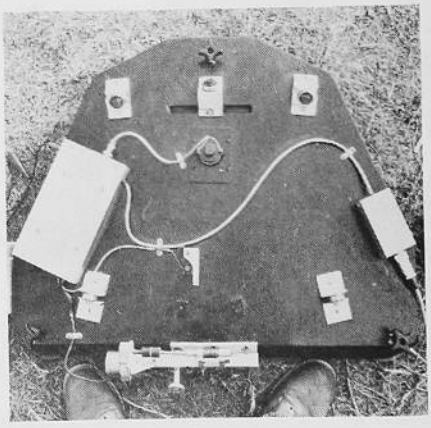
Terry Alford made a wooden lens cap with white pine, masonite, and a 1/4-20 Nylon thumbscrew. He recommends Kiwi liquid shoe polish for blackening wooden parts. His home-made shake-enders are 4-inch PVC pipe with an oak insert seated in bathtub caulk compound. Robert Peterson's computer-assisted Odyssey 10.1 uses a steel altitude "circle" held by magnets. It pivots on a small pin set in the bolt. Both axes are lit by LEDs.



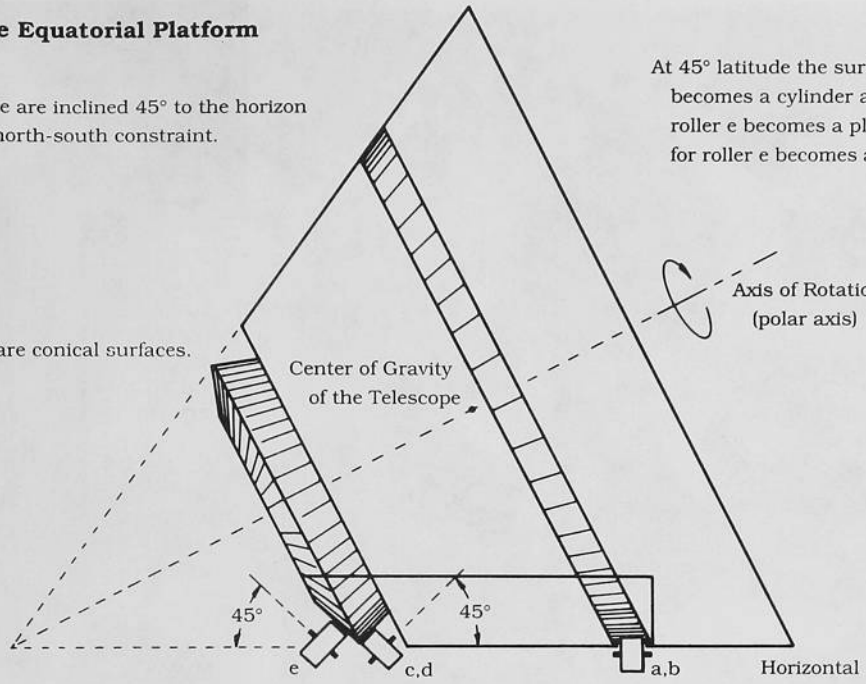






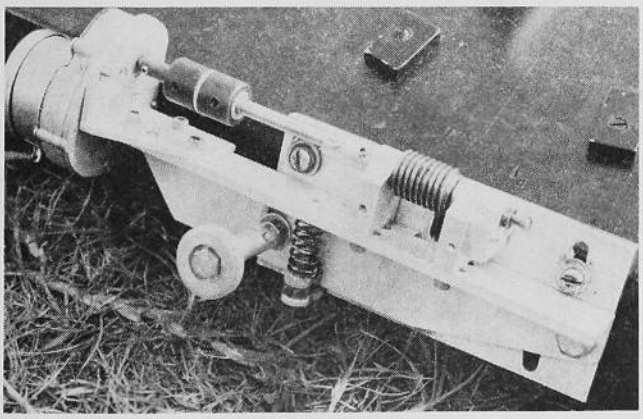


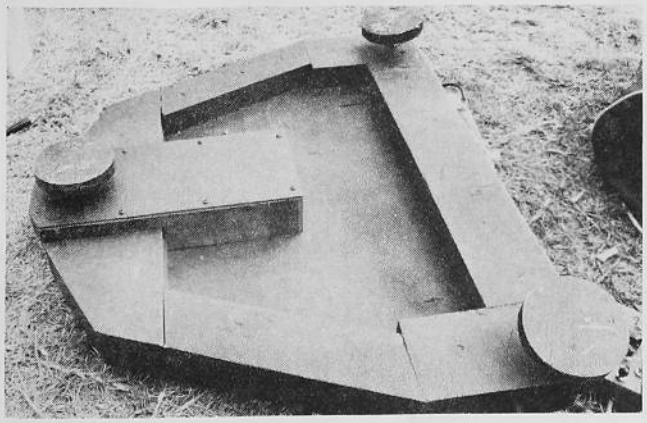
The d'Autume Equatorial Platform

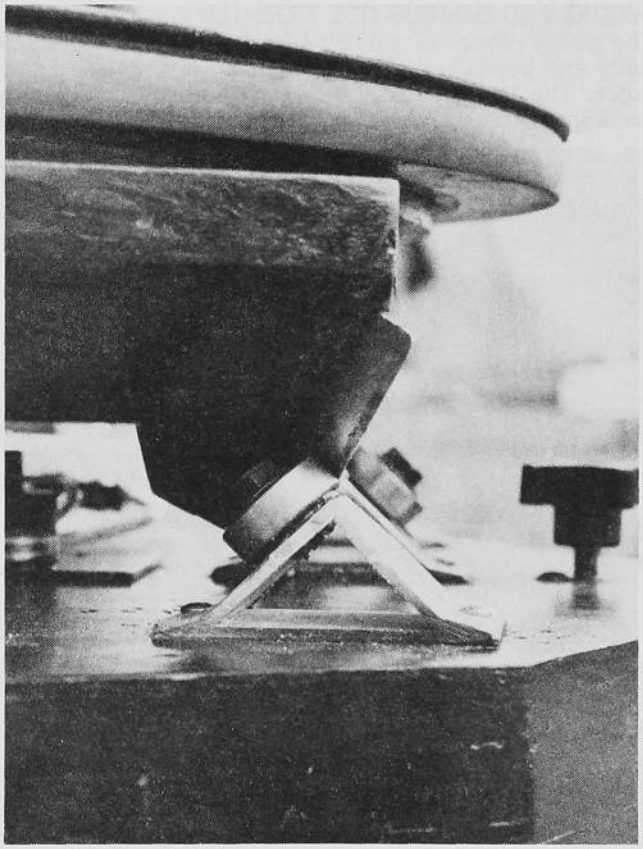


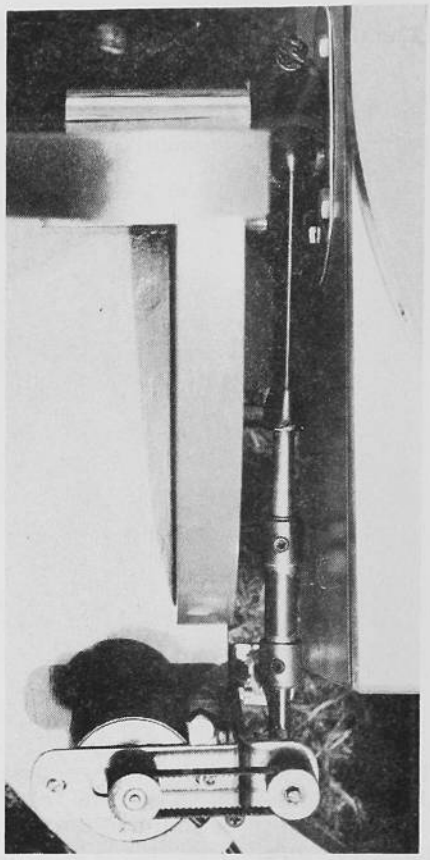
...the Equatorial Platform Comes of Age

The equatorial platform of Georges d'Autume is a step beyond other platform designs. As explained by Andy John of Jupiter Telescope, this "pivotless table rotates constrained by at least five surfaces and all five surfaces are figures of revolution about a common virtual axis." Shown in the pictures is the prototype system Johnson has constructed. The table is held only by gravity, and the axis of rotation passes well above the table surface.



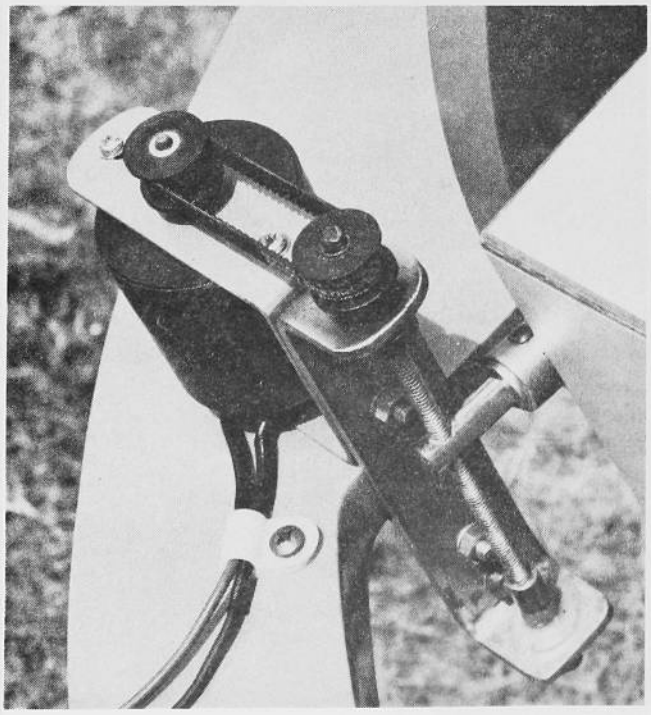


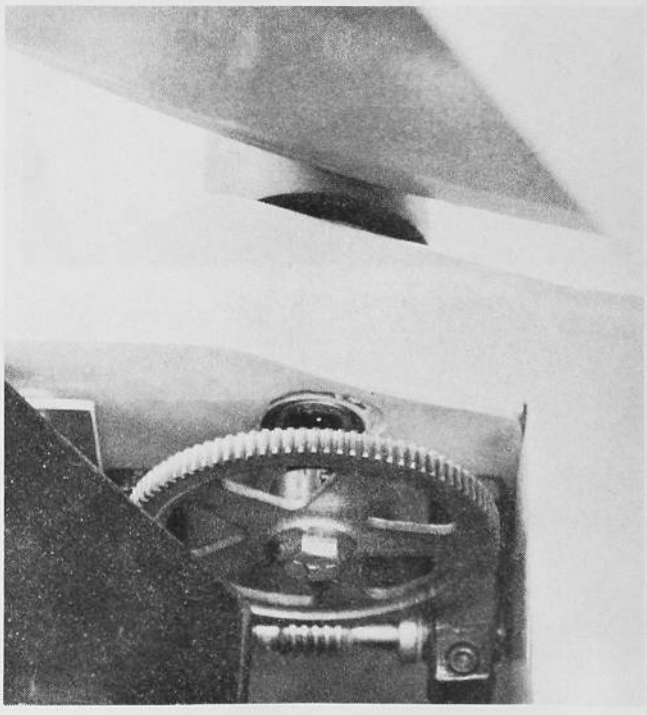


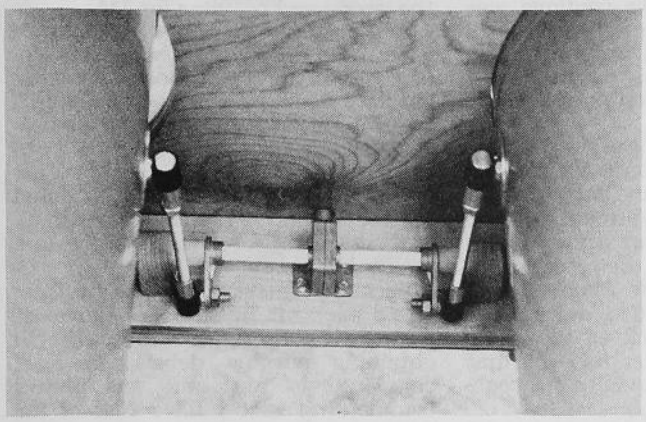


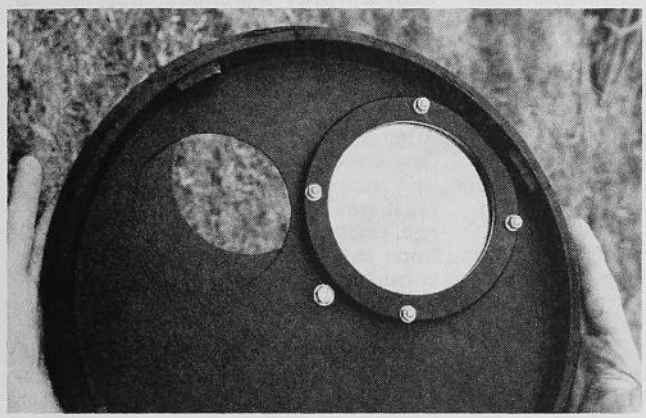
Would You Believe It's a DS-10?

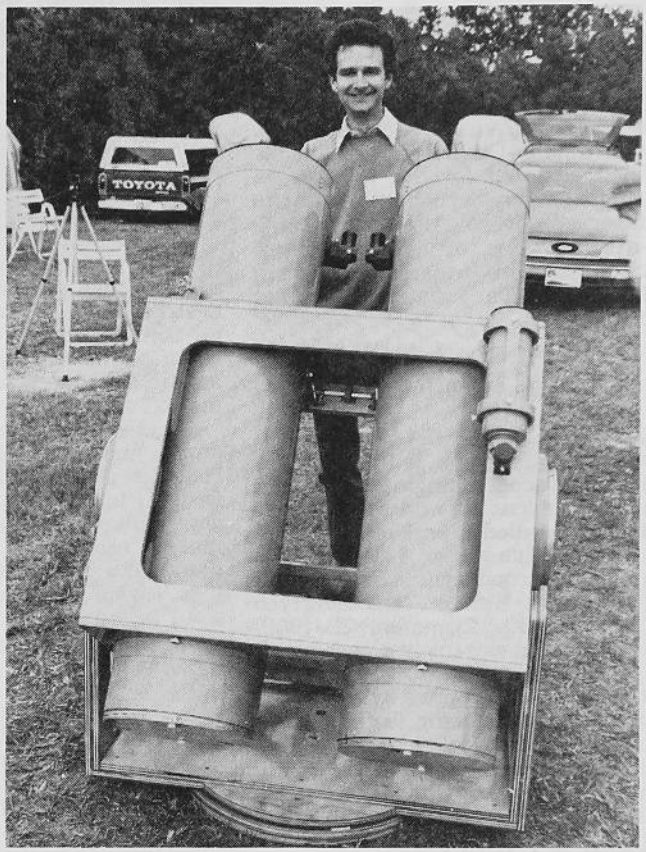
The glossy paint conceals a highly modified DS-10. James Horne (in photo) and John Rumbley's goals were stability and bypassing machine shops. For the declination slow-motion mechanism, the nut slides in a VW valve guide. The RA drive is a skateboard wheel driven by a 96-tooth Boston gear. Cutting of split-ring parts was accomplished with a router; principal materials used are birch plywood and construction-grade lumber.





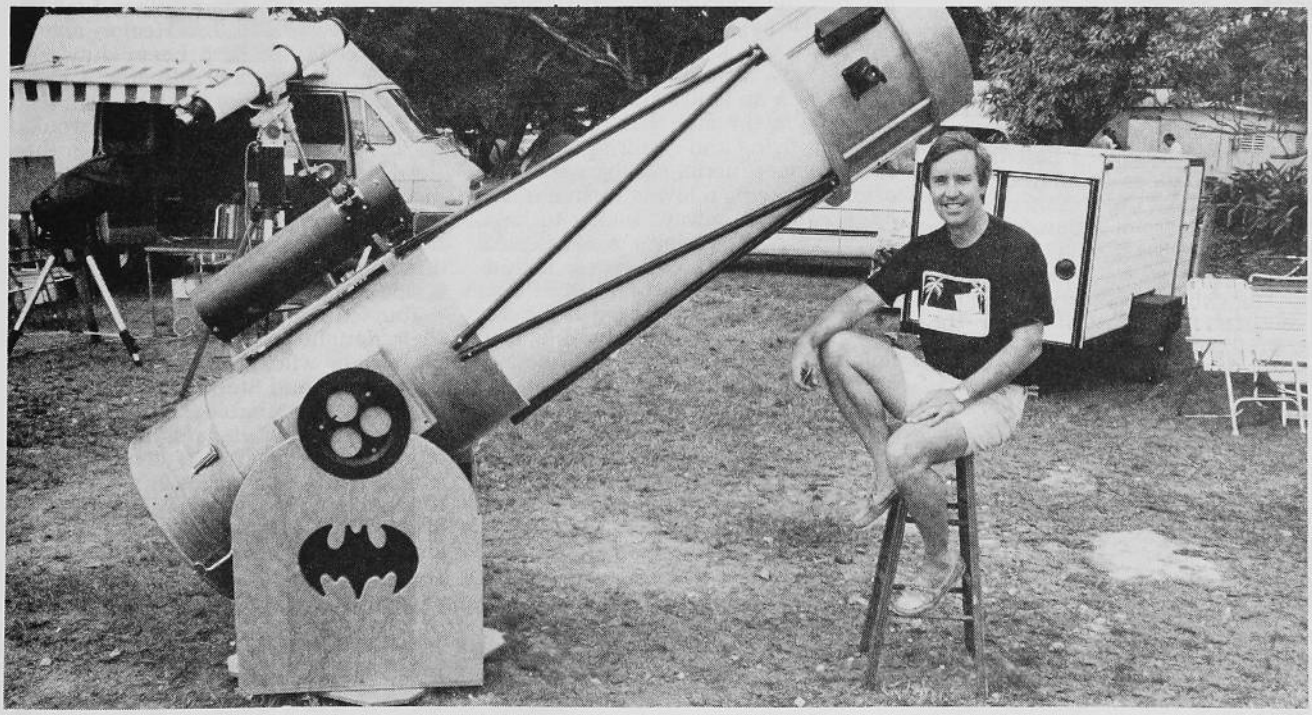






Two-Tube Binocular Telescope...and the "BatScope"

Franklin Morgan brought his just-completed 10-inch binocular. To make the optics easy to adjust, the tow optical trains are housed in separate tubes that can be rotated with a window crank mechanism to set the interocular spacing. For viewing the Sun, Morgan has installed solar filters in wooden tube covers. These won't blow off in a breeze. David Knowlton incorporated the infamous bat emblem in his 20-inch f/5 Dobsonian.



Letters

presented.

The next step for me is to be able to run spot diagrams of Yolo systems. Has anyone out there mathematically defined a toroid for the purpose of tracing skew rays? I'd hate to have to re-invent the wheel. How about tilted off-axis portions of conic surfaces, such as exist in Jose Sasian's 5-inch f/8.6 Yolo? It's mind boggling at times.

David Stevick
2224 Charles Street
Wellsburg, WV 26070

Tessar Makes Good Copyscope

Dear Richard/In the fall of 1987, I built a copyscope using a surplus Fujinon copier lens. It worked so poorly that I dismantled it and built a small Newtonian. This winter, I attempted to build a copyscope again, this time using a Zeiss Tessar lens (Jerryco #2046, $24.50, Evanston, IL (708) 475-8440). I'm extremely pleased with its performance.

It seems that copiers without the enlarging and reducing feature use a simpler symmetrical lens assembly which is not well corrected at infinity focus. I don't know which copiers are which, but can vouch for the Zeiss Tessar.

David Beard
R.D. #1, Box 648
Newmanstown, PA 17073

Does Enhanced Silver Last?

Dear Richard/I am writing this letter to you and TM to give amateur astronomers some food for thought if they are considering enhanced silver coatings for their mirrors. Two years ago I spent a fair amount of money and had my 8" f/6 Newtonian main mirror and its diagonal mirror coated with enhanced silver coatings. I had the old aluminum coatings removed form both mirrors. I got the enhanced silver coatings because of manufacturer's claims about 98% or so reflectivity (*versus* 88% or so for regular aluminum). The extra reflectivity of the silver coatings proved itself under the dome of the heavens. I was able to view +11.0 magnitude comets with this scope as well as +14.2 magnitude stars using a variable star chart.

Today my enhanced silver coatings are breaking down and tarnishing. The protective overcoat is gone and my silver coatings are slowly turning to a grey black color. My diagonal mirror is the worst of the two mirrors with several "chicken pox" marks of tarnish across its face.

The main mirror is in better shape with a "tarnish crescent" on one edge of the mirror. I estimate that I've got one more good year of observing with the mirrors before the tarnish takes its toll.

You may be thinking that the breakdown of the protective coatings was due to improper cleaning methods. I have only cleaned the mirrors three times since I got them recoated and I only use distilled water as a cleaning agent.

I contacted the University of Vermont about this problem. I found out that Vermont has very concentrated acid rain. Not only Vermont has an acid rain problem, but an acid dew problem as well. It is the researcher's opinion that acid dew attacked and destroyed the protective overcoating on the mirrors as well as the silver coating. The researcher told me that acid rain and dew attacks paint coatings on automobiles too.

I have not seen any written material on life expectancy of enhanced silver coatings. Perhaps other amateurs can write in to TM with their experiences with enhanced coatings. I want to make it clear that I do not blame the manufacturer who supplied the coatings. However, telescope makers may want to think twice before having enhanced silver coatings put on Newtonian mirrors.

Gary Nowak
Vermont Astronomical Society
38 Thasha Lane, #L-1
Essex Junction, VT 05452

Tom Greska 1940-1990

Tom Greska, a long-time member of the Polaris Observatory Association, died in the crash of his light plane in Ventura County, California, on February 19, 1990. His partner in their aerial photography business, Greg Madonna, was also killed in the crash. At the time of his death, Tom was just a few months short of his fiftieth birthday. He was in the process of purchasing a well-known business at the Santa Paula Airport, AiRepair, Inc.

Tom was an active member of Polaris, despite the fact that he was also active in flying and restoring light aerobatic planes, aerial photography, and of course, being a loving husband and father. He was always happy to help, and served the Polaris Astronomical Society in various capacities, including Chairman in the mid-80s. Tom didn't mind doing his share of the dirty-work, as exemplified by his also holding the ever-popular Clubhouse-keeping Chairmanship of Polaris.

Tom was a very talented designer and craftsman. I remember first seeing his elegantly designed 8-inch Newtonian reflector, and commenting: "Wow, that looks like it was designed by a builder of yachts!" Tom's reply was that he had been employed as a marine architect several years earlier. You can see a picture of Tom with that telescope on page 48 of *Build Your Own Telescope*. He also built a wonderful 17.5-inch Newtonian mounted on a very stout wooden fork, and housed in a building he also designed and built. Arnie Richards and I have agreed to write an article about the 'scope and building for *TM*.

As I got to know him, I also learned that Tom had been a designer of mobile homes for Fleetwood Industries. Much to my surprise, I discovered that I had lived in one of his award-winning designs in the mid-70s! I can testify to Tom Greska's skill as a designer, because the use of space and the comfort of his Fleetwood design almost made me forget I was living in a mobile home.

As many TMs are wont to be, Tom was a pack rat for telescope parts. He exercised considerable discipline in obtaining surplus debris, at least compared to me, and was always commenting that I have half of the C&H Surplus Warehouse packed into my garage. I commented back that it was easy for him to make that claim, in view of his legendary raids on my garage in search of just the right widget or gramus for his latest project. After Tom's funeral, his twin brother Charley and I reminisced about the last time the three of us were together. It was about a year ago in my garage, during one of Tom's raids. (Tom, I hope your spirit makes more than an occasional raid on my shop. I've always admired your skill and craftmanship.)

I'm honored that Tom Greska chose some of my best surplus finds to be part of his telescopes. I also note that he gave as good as he got. The following story illustrates my point: Some years ago, I talked Tom out of two of three solid-aluminum spars which had been made for the wings of a high-tech jet fighter. Tom had traded something to a friend who worked for Northrup for the spars. When I spoke to fellow Polarisite Jim Heaton about his project to make a heavy-duty tripod for his 7.5-inch refractor, I suggested that he make the legs from the two spars I now had, and that I would speak to Tom about obtaining the third spar. It didn't take much talking. When Tom realized what a wonderful tripod the spars would make, he gave the third one to Jim, also. Jim's telescope won an award at Riverside the next year.

Tom leaves his widow, Caroline, and their daughter, Elise. He also leaves his former wife, Pam, and their children, Brian and Stephanie. Tom's first wife, Teri, was unable to attend his funeral, but one of her relatives attended, and spoke in Tom's memory. Tom was a loving and caring husband, father, and friend to all of them. The priest officiating at the service read a lovely parting letter Caroline wrote to Tom. Everyone who was part of Tom Greska's too-short life will miss him very much.

Richard D. Shaffer
228 E. Pentagon St.
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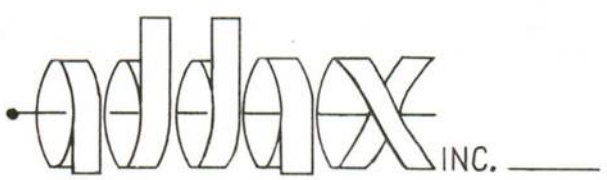

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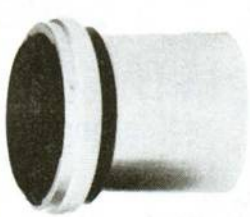

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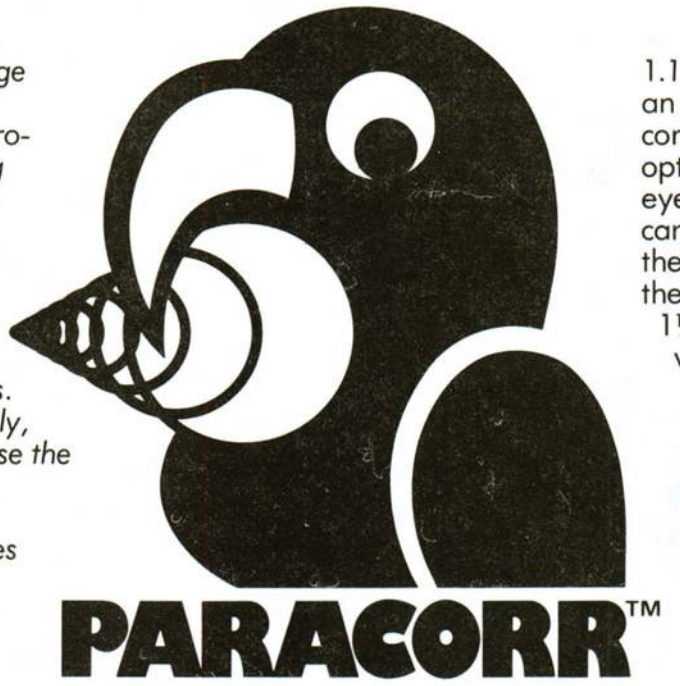

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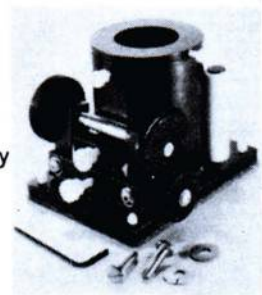

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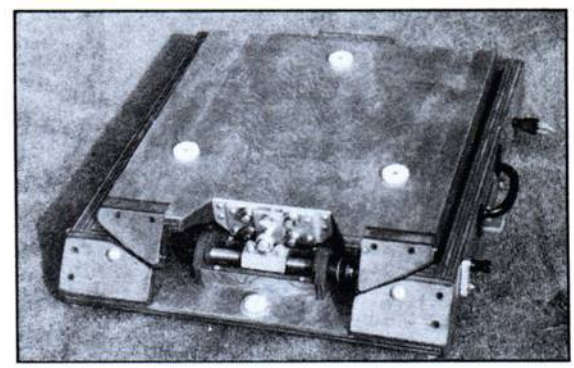

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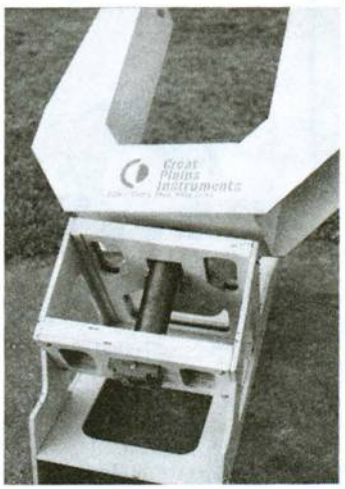

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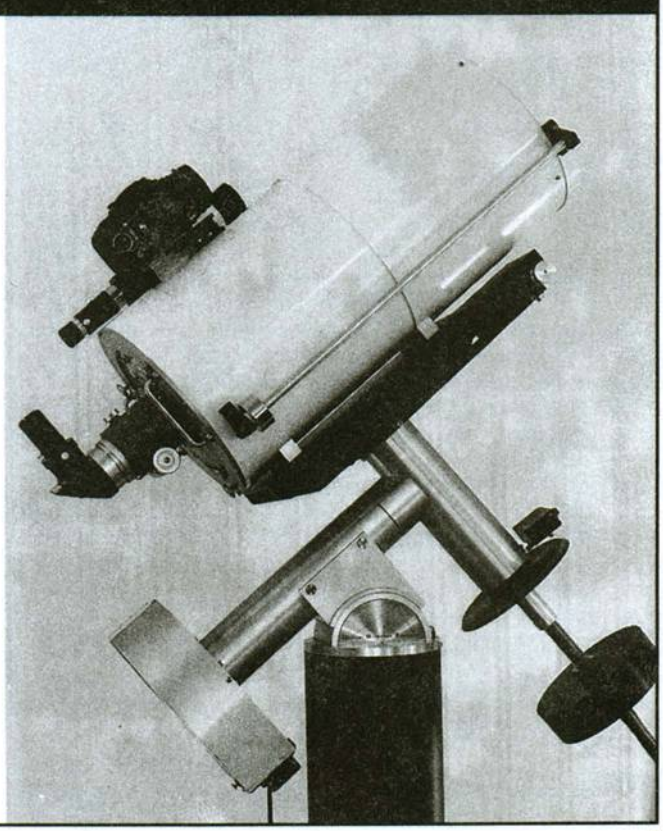

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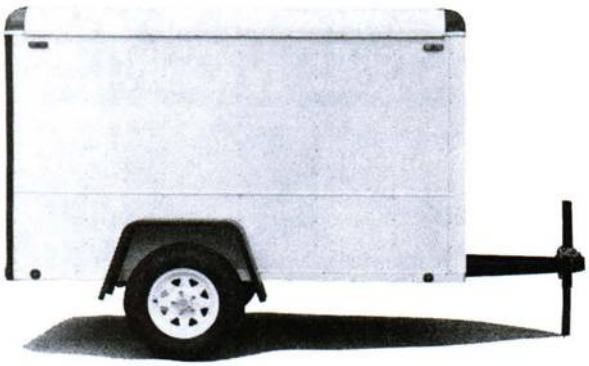

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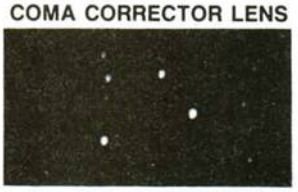
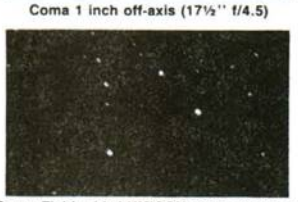


Coma 1 inch off-axis (17½" f/4.5)



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Prices subject to change w/o notice.

NEW! ENCHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

LUMICON 1.3" & 3.1" enhanced silver diagonal mirrors & 2" star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave.

1.32" **$29.95** 1.52" **$34.50** 1.83" **$39.50**
2.14" **$49.50** 2.60" **$65.00** 3.10" **$89.50**

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.
1¼" (1.32" mirror) **$99.50**
2" (1.83" mirror)(see photo above) .. **$159.00**

OXYGEN-III FILTER

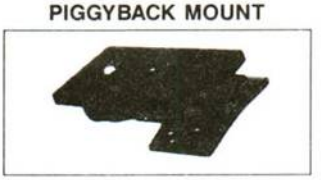
Helix Nebula, NGC 7293 in Aquarius. Bright and easy with Lumicon Oxygen-III Filter.

The ultimate in filter performance! The Lumicon Oxygen-III Filter has a contrast twice as high as the high performance Lumicon UHC Filter™. Use the Oxygen-III Filter for observing the very faintest planetary and diffuse emission nebulae. Also gives incredible views of bright nebulae (like M-27, M-17, etc.) from urban locations. Bandpass is 11nm, transmission is 90% for both O-III lines at 496nm and 501nm.

Filter Type	1¼"	48mm
Lumicon Oxygen-III	$99.50	$199.50
Lumicon UHC	$99.50	$199.50
Lumicon Deep-Sky	$79.50	$119.50
Set UHC and Oxygen-III	$190.00	$380.00

NOTE: The Oxygen-III Filter is not a substitute, but a compliment to the UHC Filter. **1 year guarantee:** You must see nebulae with the O-III filter that are **invisible** without a filter.

NEW ADJUSTABLE PIGGYBACK MOUNT



LUMICON has just designed a new adjustable piggyback mount ideal for all telescopes of 8-14" aperture. It has **both** vertical and sideways adjustment to allow optical alignment. It was designed to allow mounting of the LUMICON SUPER-FINDER on C-8, C-14, etc., but is ideal for any telephoto lenses or small telescopes.

Deluxe Piggyback Mount **$54.00**
(State Telescope Type)
LUMICON 12x80mm SUPER-FINDER $195.00

NEW! LOW PROFILE HELICAL FOCUSERS

LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6" telescope.
LUMICON now offers 3 different low-profile helical focusers. They stand only 1¼-1½" above the telescope tube. Use the 1¼" or 2" versions for viewing. Use the 2" non-rotating focuser for convenient photography with the LUMICON 2" EASY-GUIDER™.
Select your desired base-plate shape!
Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.
LUMICON 1¼" Helical Focuser **$49.50**
LUMICON 2" Helical Focuser **$59.50**
LUMICON Non-rotating Helical Focuser $89.50
3 handles (see photo) for non-rotat. focuser **$12.95**
2" Rack & pinion low profile focuser ... **$129.00**
2"/1¼" adapter w/48mm filter threads ... **$20.00**
2" LUMICON EASY-GUIDER **$169.50**

PROTECTIVE DUST COVERS

Protective plugs (left), vinyl dust covers.
Protect your valuable telescope optics, eyepieces and accessories with these black vinyl covers. Add $1 shipping. Deduct 10%, 2 or more sets.

1¼" O.D. plug, seals focuser ..... **4/$2**
2" O.D. plug .. **2/$2** 3½" O.D. plug **$1.50**
1¼", 1⅜" ... **3/$2** 7½" **$8**
1½" ..... **2/$2** 9½", 10.4"* ... **$12**
2" ..... **2/$2** 12½", 12⅞"* ... **$15**
3½", 4½" ... **$5** 16"* **$20**
5½" ..... **$6** 19" (DS-16) ... **$35**
*Fits Odyssey 21" (Odyssey 17½) **$35**

MAKE YOUR OWN ASTROGRAPH

FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

†U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds **$295.00**

MODEL 600 HYPER-KIT (See Photo) Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates **$350.00**

MODEL 1200 HYPER-KIT is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller **$595.00**

Temperature controller for any HYPER-KIT **$65.00**

Electric Vacuum Pump **$319.00**

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X easier guide-star selection, use 48mm filters, 360° camera rotation, large prisms of bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent #4,448,500

NEWTONIAN EASY-GUIDER™

Full aperture. Installs in secs. Specify 2" or 1¼".
NEWTONIAN EASY-GUIDER **$169.50**
3X Relay Diagonal (see photo) **$89.50**
Illuminated reticle eyepiece system ... **$99.50**
Guider for Hasselblad **$350**, Mamiya 645 **$199**

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation —3X shorter exposures! **Superb rich field viewing, too!**
CASSEGRAIN EASY-GUIDER **$225.00**
Adapter for Hasselblad $185, Mamiya 645 **$98**

GIANT EASY-GUIDER™

For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER **$395.00**
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20) ..... **add $99.95**
Adapter for Hasselblad adapter **$195**, Mamiya 645, **$119**

WHAT DO YOU NEED?

1. Illuminated reticle eyepiece **$99.50**
Lumicon 12mm eyepiece system has adjustable L.E.D. illumination, dual crosslines, battery pack.

2. Cable release for long exposures ... **$9.95**

3. **LUMICON Quartz Drive Corrector . $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.
Declination motor (state telescope) .. $99
NEW Deluxe Digital Qtz. Drive Correc. **$298**

HYPERSENSITIZED FILM
LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	Exposures	Price
2415, Ultra-fine B&W, red sens.	36	$10.95
SR3200, fastest of all, color neg	24	$13.95
Konica SR400, fine gr. color neg	12	$10.95
3M 1000, fastest slide film	20	$12.95
Fujichrome RD100, fine gr. slide	24	$12.95
5072, color slides from negs	36	$6.95
D-19 B&W Developer	1 gal.	$6.95

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